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1926

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I. INTRODUCTION.

The object of this study is to investigate the practical applications of the principles developed by Dr. Sverre Petterssen in "Kinematical and Dynamical Properties of the Field of Pressure, with Application to Weather Forecasting". In addition an endeavor will be made to demonstrate the use of this method in studying the movements of West Indian Hurricanes as they approach the United States.

"Practical Rules for Prognosticating the Movement and Development of Pressure Centers", by the same author, was used in conjunction with the above reference in carrying out this investigation.

To carry out this plan we have selected two separate weather situations for analysis, namely 20-25 August 1933, and 13-19 September, 1933. These series were selected because they represent two well developed West Indian Hurricanes approaching the East Coast of the United States. The first of these series presents an opportunity to study the behavior of a hurricane on the continent; the second, that of one, which, while remaining at sea, is close enough for its influence to be felt on the continent. In addition we have an opportunity to attempt to correlate their movements with those of the pressure systems over the United States.

The data entered on these maps were taken from the original barograph traces of the various stations. These traces were kindly made available by the U. S. Weather Bureau. En-

tries were restricted to pressures and tendencies for the two previous three hour periods, in order to make reproductions as clear as possible. Entries were made in the following order, pressure on top or in the station circle, next the pressure change for the three hour period ending at observation, lastly the pressure change for the three hour period preceding.

Fronts are drawn as heavy solid lines, isobars as lighter solid lines, isallobars for the period ending at observation as dashed lines and isallobars for the preceding period as dotted lines. Isallobaric Highs are marked R and + corresponding to dashed and dotted isallobars respectively. Similarly, isallobaric Lows are marked F and (−). Numerical calculations being based on pressures and changes of pressures, this information is sufficient for the purposes of this work, provided the regular surface maps have been analyzed by the usual methods, which of course enables us to locate any fronts which are present.

The authors take this opportunity of expressing their appreciation for the assistance and advice given them by Dr. H. C. Willett, Mr. Gardner Emmons, and Mr. H. Olsson in the original analysis.

Especial thanks are due Professors C. G. Rossby and H. C. Willett of the Massachusetts Institute of Technology for their helpful advice in the preparation of this paper.

The opportunity of studying the applications of these methods under Dr. Sverre Petterssen during the summer of 1935 was of invaluable assistance.

II. SYNOPSIS OF THE METHOD.

No attempt will be made to explain the derivations of the formulae used in this method, but it is believed that a collection of formulae with essential notations and definitions will be helpful to the reader.

The following symbols are used throughout

t = time

T = tendency

ΔT = change in tendency with time

P = Pressure

∂ = partial differentiation with respect to a fixed system of coordinates

δ = Partial differentiation with respect to a moving system of coordinates.

C = velocity; C_L = velocity of a line (trough, wedge)

C_f = velocity of a front

h = Distance between two neighboring unit isobars, along a straight line.

A = Acceleration

S = Displacement

Points on the map used in computations are lettered for purposes of identification and are not to be confused with the above symbols.

Definitions.

Ascendant - Where using the term "Ascendant" of a property we mean the increase of that property with respect to space.

The ascendant of any scalar field is a vector quantity, everywhere perpendicular to the iso lines of the property under consideration. The term "Gradient" means the decrease in the property with respect to space.

"Effective tendency" is the algebraic difference between the observed tendency and the tendency due to the diurnal pressure variation at that station for the same period.

$$T_{Effective} = T_{observed} - T_{diurnal}$$

"Tendency" is the variation of pressure with respect to time only. It is reported as the net change in pressure in a time interval of three hours. Thus when t enters a formula, it is taken to mean a number of three hour intervals or tendency periods.

$$\Delta T = T_{Now} - T_{previous\ Tendency\ Period}.$$

"Deepening" is a decrease in pressure of any system.
"Filling" is an increase in pressure of any system.
"Characteristic line" is an identifiable line on the map, i.e. isobar, trough, wedge, front, isallobar, etc. Thus the center of a pressure system becomes the intersection of two characteristic lines and is known as a characteristic point.

Velocity formulae.

Isobar. $C_i = -Th$ where h is the perpendicular distance between unit isobars.

Front.

$$C_f = -\frac{\frac{\partial P_1}{\partial \tau} - \frac{\partial P_2}{\partial \tau}}{\frac{\partial P_1}{\partial x} - \frac{\partial P_2}{\partial x}}$$

Subscript 1 refers to the area in advance of the Front, 2 refers to that area behind the front.

Center of Low, Center of High, Trough or Wedge $\Bigg\}$ $C_L = - \dfrac{T_{\frac{1}{2},0} - T_{-\frac{1}{2},0}}{P_{1,0} - 2P_{0,0} + P_{-1,0}}$

$T_{\frac{1}{2},0} - T_{-\frac{1}{2},0} = \frac{1}{2}\left[T_{1,0} - T_{-1,0}\right]$ as an alternate formula for application when unit chosen is less than three degrees of latitude. The advantage of using this formula is that the value of the tendency is not taken at a point immediately behind the trough line.

Occluding velocity

$$C_c - C_w = \frac{\frac{\partial P_1}{\partial \tau} - \frac{\partial P_2}{\partial \tau} - \frac{\partial P_3}{\partial \tau} + \frac{\partial P_4}{\partial \tau}}{\frac{\partial P_1}{\partial x}}$$

Acceleration Formula

$$A = - \frac{(\Delta T_{\frac{1}{2},0} - \Delta T_{-\frac{1}{2},0})(P_{1,0} - 2P_{0,0} + P_{-1,0}) - 2(T_{\frac{1}{2},0} - T_{-\frac{1}{2},0})(T_{1,0} - 2T_{0,0} + T_{-1,0})}{(P_{1,0} - 2P_{0,0} + P_{-1,0})^2}$$

This is the most convenient formula for use as an approximation.

Deepening and Filling.

$$T_{deepening} = T_{observed} - T_{diurnal} - T_{Movement}.$$

Displacement.

$$\delta = C\tau + \tfrac{1}{2}A\tau^2$$

Choice of units.

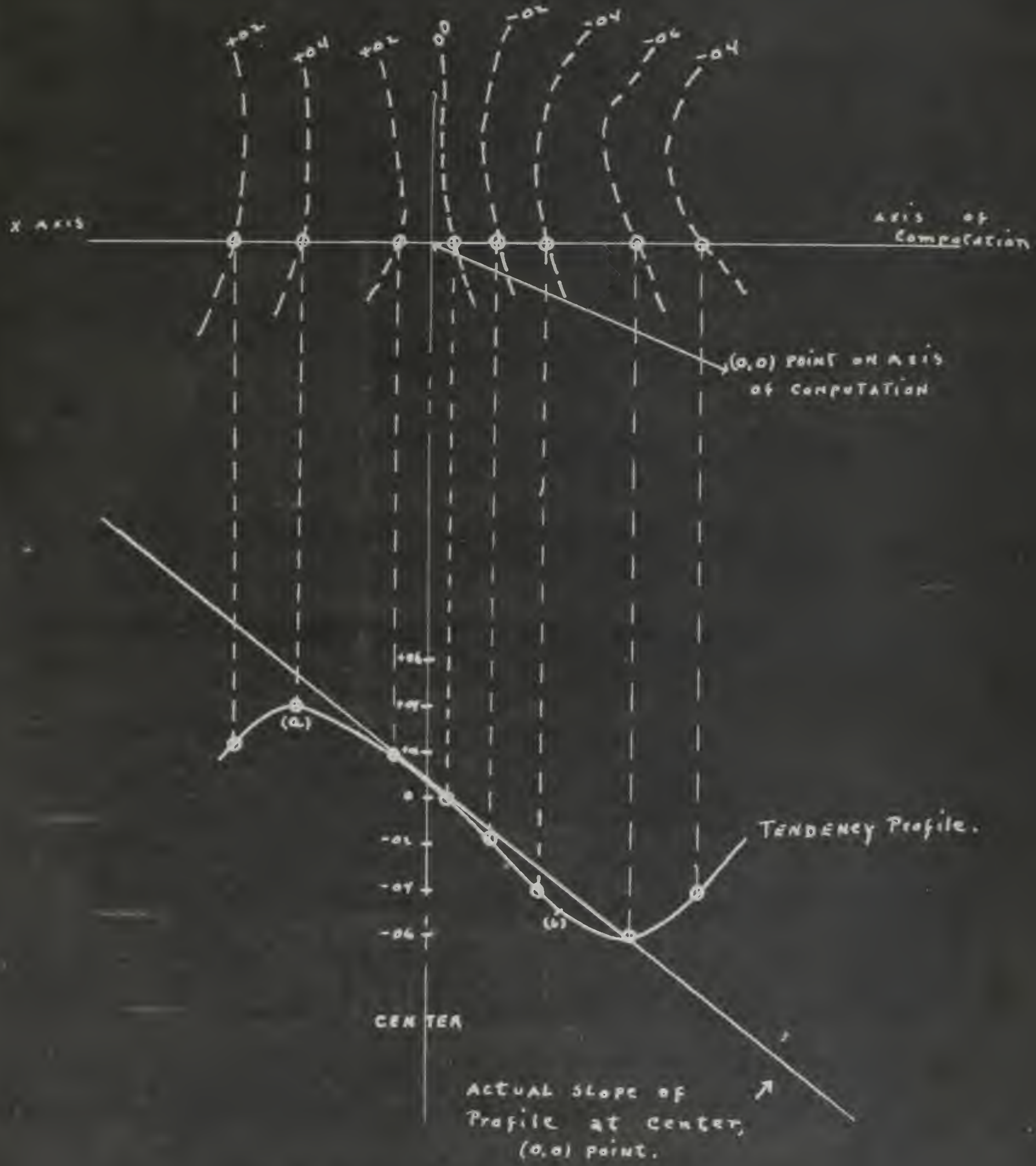
Inasmuch as all the above formulae are in terms either of slopes or curvatures of certain lines, and as the method of numerical differentiation is an attempt to approximate the slopes or curvatures at certain points, we must take some means to make this approximation as nearly exact as possible. To do this it is necessary to know the pressure and tendency profiles in the

region where the computations are to be made. In practice it is usually unnecessary actually to draw these profiles except in extreme or borderline cases, as with practice one becomes able to visualize that region over which the slope is fairly constant.

The first step in the choice of the length of our unit is to draw the tendency profile in the following manner. Having previously drawn in the smooth isobars and isallobars, we choose an axis along which we wish to make our computations. We draw a set of rectangular axes on a piece of paper and draw the profile as shown in the sketch. It will be noticed that the abscissae are actual horizontal distances along our axis of computation, while the ordinates represent tendencies to any convenient scale. A smooth curve is drawn thru the points so plotted. This profile will show up inconsistencies in the drawing of the isallobars as it should be smooth and continuous rather than jagged.

From inspection of this profile we decide on the maximum length of unit possible. This is governed by the distance over which the profile remains practically a straight line. The formulae for velocity are based on the slope of the tendency profile, those for acceleration contain both the slope and the curvature. We must choose our unit so that we make the closest approximation to the true differentials. On the tendency profile sketch, the points (a) and (b) denote that portion of the curve where this approximation maintains.

If we are making velocity computations only, we are concerned with the tendency profile between the points $(-\frac{1}{2}, 0)$



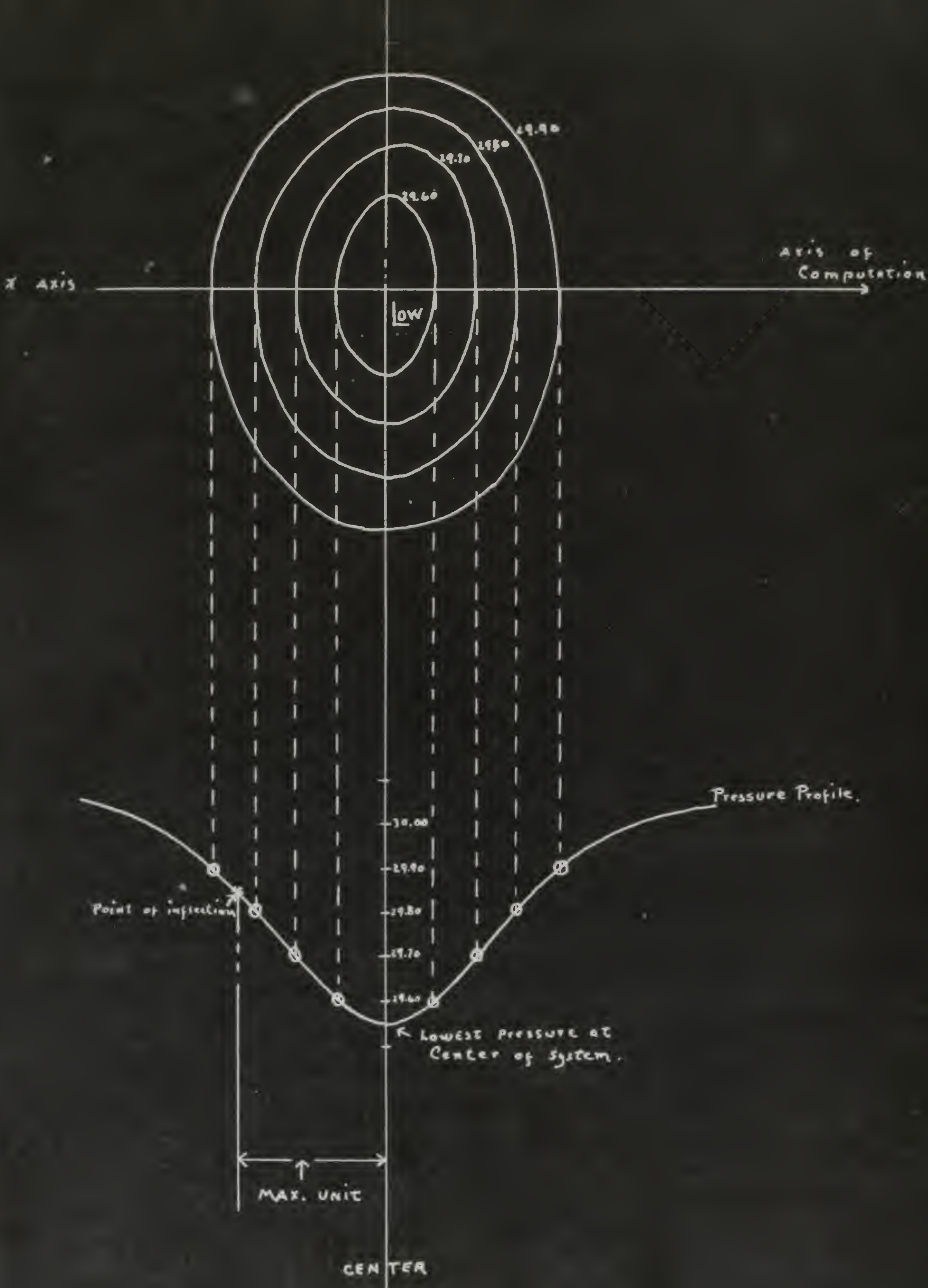
TENDENCY Profile.

and $(\frac{1}{2},0)$. Hence this length between (a) and (b) along the X axis will represent the unit length, that is, the distance from $(-\frac{1}{2},0)$ to $(\frac{1}{2},0)$.

Now, if we wish to make computation of acceleration, we are concerned with the tendency profile from $(-1,0)$ to $(1,0)$, so, our distance (a) to (b) is twice our unit length. Care must be taken that units used for velocity and acceleration formulae are reduced to a common value for use in the displacement formula. This obtains when different units are used in the computations of acceleration and velocity.

It will be noticed in the tendency profile sketch that the curve does not necessarily cross the ordinate axis at a tendency value of zero. The reason for this will be seen in the discussion of deepening and filling.

After drawing the tendency profile we draw the pressure profile in a similar manner. The formulae contain only the curvature of this profile. This forces us to remain within the space between the two points of inflection. The distance, then, between the points of inflection is twice the maximum unit length permitted by the pressure profile. The final unit chosen will be a compromise between that shown to be advisable by the tendency profile, and that from the pressure profile. As the tendency carries much more weight than does the pressure in the formulae, the unit should be chosen so as to give the closest approximation to the tendency profile. Usually the pressure profile shows a larger possible unit than the tendency profile and the choice in nearly all cases is based



Pressure Profile.

on the tendency profile.

It is seldom advisable to choose a unit length of less than three degrees of latitude because when so doing, the points chosen may be subject to the following tendency errors:

1. Since tendency values are taken for three hour periods, the passage of the trough may influence these values because of the pressure variation before and after its passage.
2. Larger units tend to eliminate errors in tendency reports and errors in tendencies due to local conditions.

In cases where it is necessary to choose a small unit, the effect of a larger unit is obtained by using the alternate formula previously listed. Care must be exercised in using this alternate formula that the points (1, 0) and (-1, 0) are so chosen as to lie within the distance (a) (b) on the sketch.

The foregoing remarks have been made to apply to an X axis. The same remarks are applicable to any other axis we may choose. The unit lengths should be selected independently by the above methods, for each axis along which computations are to be made.

Drawing Isobars and Isallobars.

Inasmuch as this method of computation is concerned solely with pressure and tendency values, it is of vital importance that repr sentative values for our formulae are picked off the chart. In order to do this we must draw the isobars and isallobars most carefully. Therefore we must draw smooth,

carefully spaced isobars, eliminating irregularities due to errors in reports but being careful to note and construct actual irregularities which are made apparent by a consistency among reporting stations. Change of slope of isobars at Fronts are of course essential. Errors in reports may be due to any of the following causes:

1. Actual error of observation.
2. Error in reduction to standard level.
3. Error in coding and decoding.
4. Error in transmission.
5. Deviation of report from actual observation due to coarseness of reporting scale.

In drawing isallobars we must remember that we are attempting to draw iso-lines of instantaneous tendency values. Since tendency reports represent a net change of pressure over a period of three hours, the reported value does not necessarily indicate this instantaneous tendency. The characteristic of each stations must be considered in order to arrive at a decision as to the instantaneous value at that station. For instance, +04 / actually indicates an instantaneous rising tendency of +04. Now -04 \/ does not indicate an instantaneous falling tendency, but actually a rising tendency at the time of observation. Also +04 /‾ indicates an instantaneous tendency of zero.

Consideration of the influences acting on the barograph at a station which has experienced a frontal or center passage within a reporting period, i.e., three hour period, will also show that the reported value is obviously not indicative of the

instantaneous value. Therefore, the tendencies at these stations are disregarded. Likewise stations that have been subject to variations in pressure due to local conditions such as thunderstorms during the reporting period are similarly disregarded.

When the network of stations in a given area is dense, drawing of isallobars is a relatively simple matter, but when we are concerned with an area of sparse reports, with large differences in tendencies between reporting stations, the matter of drawing isallobars becomes very difficult. However, the same area and network with uniform tendency reports at the stations would indicate that we could rely on the uniform tendency value in that area. So, in the United States, we must consider each case as distinct in determining the reliance we can place on the isallobars we have drawn. For this reason we are sometimes unable to make computations in certain regions.

When drawing isallobars in the vicinity of a Front we must remember that they are discontinuous at the Front, and that the tendency reported at any station along the path traversed by the Front in the last three hours is not the true tendency. Therefore we must draw our isallobars first from points well in advance of the Front back to it and then from points well in the rear of the front to the position which was occupied by the Front three hours previously, and finally in a smooth continuous curve from these points, across the three hour frontal path to the rear side of the present position of the Front. That is to say, the the tendency reports in the whole area swept over by the Front in the three hours previous to the reports are completely disregarded,

both in drawing the isallobars and in evaluating the formulae.

Limitations of the Method.

While the formulae developed and used in this method are mathematically correct, their applications to the weather map are useful only when used in conjunction with the broad consideration of the general pressure distribution. That is to say, ordinary judgment must be used in extrapolating velocities. For instance, a rapidly moving Low Pressure system would not be extrapolated into a large slowly moving High Pressure area. Likewise it must be remembered that the results we obtain by use of the formulae are only as correct as the approximations we make to the true differentials. Therefore, an understanding of the derivation and physical significance of these formulae is essential to their intelligence use.

In applying this method, four general types of situations arise wherein numerical computations are not practical. These are:

1. Sparse network of reporting stations in the region under consideration makes the drawing of isobars and isallobars unreliable.
2. Regions of high altitude where large pressure reductions to the reference plane result in fictitious isobars.
3. Regions where determination of instantaneous tendencies are impossible.
4. Regions of very flat pressure, here the determination of the curvature of the pressure profile is impractical because of its small value.

III VELOCITY COMPUTATIONS.

The computations of most practical daily use are those involving the velocities of Fronts, troughs, wedges, centers of Lows and Centers of Highs. This discussion will be limited to these types.

Velocity of a Front.

Any point where an isobar intersects a front is most convenient for computation of velocity. The axis along which computation is made should be chosen in the direction of motion of the Front at that point. For convenience, whenever possible, we choose our axis along the straight portion of an isobar directly in front of, or directly behind the front. The axis should lie along the isobar at least for a distance e ual to the length of the axis intercepted between neighboring isobars on the other side of the front. As $\frac{\partial P}{\partial x}$ along an isobar is zero, one of the members of the denomination vanishes.

Formula for velocity being

$$C_f = - \frac{\frac{\partial P_1}{\partial t} - \frac{\partial P_2}{\partial t}}{\frac{\partial P_1}{\partial x} - \frac{\partial P_2}{\partial x}}$$

we see that it is simply the difference in tendencies before and behind the front, divided by the difference in pressure ascendants before and behind the front. The use of differentials indicates that the values should be infinitely close to the Front. To approximate this, we must use finite differences as close to the Front as possible. We designate a basic pressure ascendant as $\frac{10}{h}$ where h represents the distance between unit

isobars along the chosen axis. The number 10 represents ten hundredths of an inch of mercury, being the pressure difference between unit isobars.

In cases where the angle between the isobar and the Front is small, or where we do not have straight isobars along which to draw an axis, we draw the axis in the direction of motion of the Front at that point. This forces us to evaluate two pressure ascendants. One of the distances along this axis between unit isobars is made the basic h, the other distance is measured in terms of this length.

Great care must be taken in determining the signs of the pressure ascendants for use in the formula. The sign is positive:

1. Going from low to high pressure along positive direction of axis.
2. Going from High to Low pressure along negative direction of axis.

The sign is negative:

1. Going from low to high pressure along negative direction of axis.
2. Going from High to Low pressure along positive direction of axis.

To determine the displacement of a Front, it is advisable to compute the velocity of several points along the Front and thereby, in plotting the displacements of these points, determine the future curvature of the Front.

Velocity of Troughs and Wedges.

Trough lines and wedge lines are mathematically similar, and remarks made concerning one are applicable to the other.

The axis for computation is selected perpendicular to the wedge line and tangent at the point of greatest curvature of an isobar. The wedge line frequently is not a straight line. The unit length is selected in accordance with the previous discussion, and the points $(1,0)$, $(\frac{1}{2},0)$ etc. are laid off along this axis with the point $(0,0)$ being that point of intersection of the axis with the wedge line.

Values at the points are merely picked off the map and inserted in the formula.

The Trough formula is not applicable to a trough containing a Front.

Velocity of Pressure Centers.

Remarks pertaining to a center of High Pressure apply equally well to a center of Low Pressure. The center of the system, being the characteristic point, is chosen as the $(0,0)$ point and through this we draw ~~an~~ our ~~axis~~ axes of computation. For a pressure center, we normally draw two sets of axes, perpendicular to each other. These axes are usually drawn along the lines of symmetry of the system. The units are chosen and applied as in the trough formula.

Displacements computed along these two axes are components of the true displacement and are resolved in the usual manner.

Rotation of the long axis of a pressure center is

readily computed by determining the difference in displacements of two points on this axis.

As a comparison of formulae, consider that of the velocity of an isobar.

$$C_i = -Th$$

This formula, while mathematically correct, should be applied cautiously for the following reason. The values chosen from the weather map for insertion in this formula are chosen at a single point on the map. Any variation in pressure or tendency at this particular point due to local influences will give a result which differs from the motion of the pressure field taken as a whole. In the application of the various formulae which have been developed in K. & D.P., the computer should bear in mind that the formula which utilizes the greatest number of points on the map will give the most reliable results, since the effect of local variations at any one point will be minimized. That is, use of a larger number of points in arriving at a result will have the effect of lessening the error which is caused by the values at one of the points being incorrect.

For this reason, the method of numerical differentiation gives the most satisfactory results. Along a given X axis, the numerical differentiation formula uses five points, namely (1, 0); ($\frac{1}{2}$, 0); (0, 0); ($-\frac{1}{2}$, 0) (-1, 0). As mentioned before, this has the effect of ironing out small inaccuracies. There-

fore we should expect to get the best results in calculating the movements of the centers of High and Low and also wedge and trough lines.

On the other hand, the formula for the velocity of a front

$$C_f = - \frac{\frac{\partial P_1}{\partial \tau} - \frac{\partial P_2}{\partial \tau}}{\frac{\partial P_1}{\partial x} - \frac{\partial P_2}{\partial x}}$$

utilizes the tendency values picked at one point on the Front and the pressure ascendants at that point. Thus, although Ismoothed isobars and isallobars are used in picking off the values at this point, any inaccuracy in arriving at the velues for this one point is reflected directly in the result. Yet this formula may be applied rapidly and mentally if the axis is chosen along the isobar on one side of the Front. The chief value, then, of this frontal formula for velocity lies in applying it at a number of points along the Front and arriving at an extrapolated position of the Front by taking a mean of the computed points. Quite frequently on weather maps, Frontal situations with weak pressure gradients or scanty pressure reports, make the exact determination of the position and curvature of an isobar impossible. In these cases, since the success of the Frontal velocity formula depends on the accuracy with which we determine the true gradient, its use is prevented.

IV. ACCELERATION COMPUTATIONS.

As computations of accelerations require the term ΔT and as this term can not be obtained from our present reports, these computations are impossible on the daily weather map at the present time.

Assuming we have the information with which to evaluate ΔT , we may use the formula listed in Chapter II for acceleration computations of Fronts, Troughs, and Centers. (See F. & D.F., page 38).

Inasmuch as the acceleration is multiplied by 1/2 the square of the time in the displacement formula, it is most important that its value be determined accurately. Accurate determination of this value is most difficult on account of the involved nature of some of the members of the formula, and also because of the approximations made in the derivation.

The term ΔT , which is the rate of change of slope of the barograph trace at a given station is usually the most important member of the formula. Its accurate determination depends on knowing the instantaneous value of the tendency at a point at two different instants. Local variations in pressure and coarseness of reporting scale are apt to influence the most carefully drawn isallobars, hence are sources of error in evaluating ΔT.

The second term of the formula contains the slope of the tendency profile and the curvature of the tendency profile which is the rate of change of slope of the tendency

profile. The fitting of units to approximate these slopes is impossible in cases where the profiles are steep and the system small. Also errors in approximating the slopes are magnified in determining the rate of change of slope.

For these reasons, as well as the time required for computation and wide variations in results due to personal judgment, it is considered that acceleration computations on the daily weather map are not practical.

V. DIURNAL VARIATIONS OF PRESSURE.

In order to determine the effect of changing pressure systems on any station, it is necessary to consider the normal diurnal variation of pressure at that station. That is to say, we wish to separate the change in pressure due to these varying pressure systems from the effect of the semi-diurnal wane of pressure, as the reported tendency is the resultant of these two effects.

The following is an extract from page 232 in Humphrey's Physics of the Air: "There are two classes of well defined, twenty-four hour pressure changes. One obtains at places of considerable elevation and is marked by a barometric maximum during the warmest hours and minimum during the coldest. The other applies to low, especially sea level, stations and is the reverse of the above. The maximum occurring during the coldest hours and the minimum during the warmest."

To obtain this information exactly we would need to consider the normal daily variation of pressure at each station. In practice we use maps on which are plotted the normal variation of pressure for the three hours preceding the 8 A.M. and 8 P.M. observations. These maps show this tendency over the United States. These maps are divided into regions of equal tendency values. They are made up for the average normal for each month of the year. For periods other than those for which the maps are drawn, we must resort to an application of the information contained in the above quotation. To do this we make use of a curve of diurnal pressure variation at a station which is representative of the area which we wish to consider,

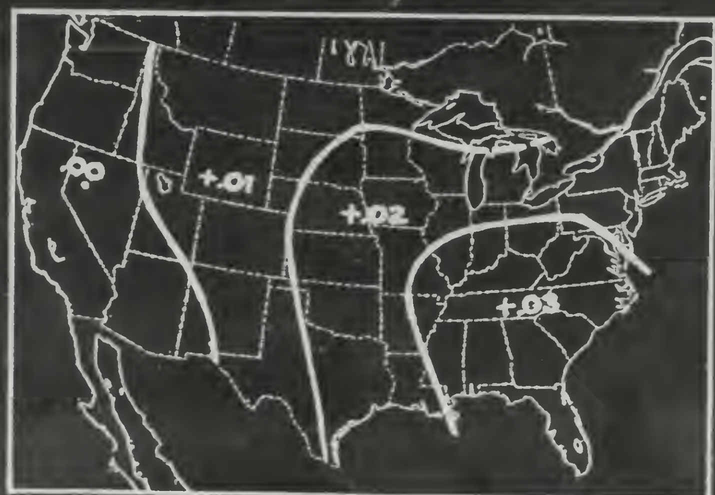
NORMAL PRESSURE CHANGE

IN THREE HOURS PRECEDING THE OBSERVATION

8:00 A. M. (E. S. T.)

August

September



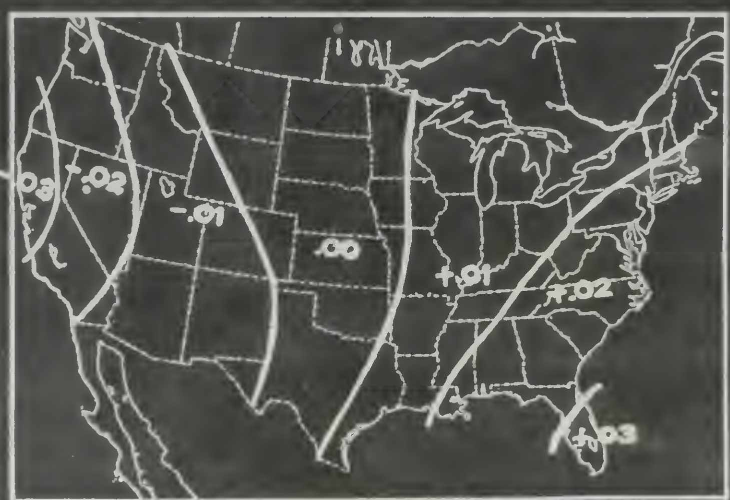
NORMAL PRESSURE CHANGE

IN THREE HOURS PRECEDING THE OBSERVATION

8:00 P. M. (E. S. T.)

August

September



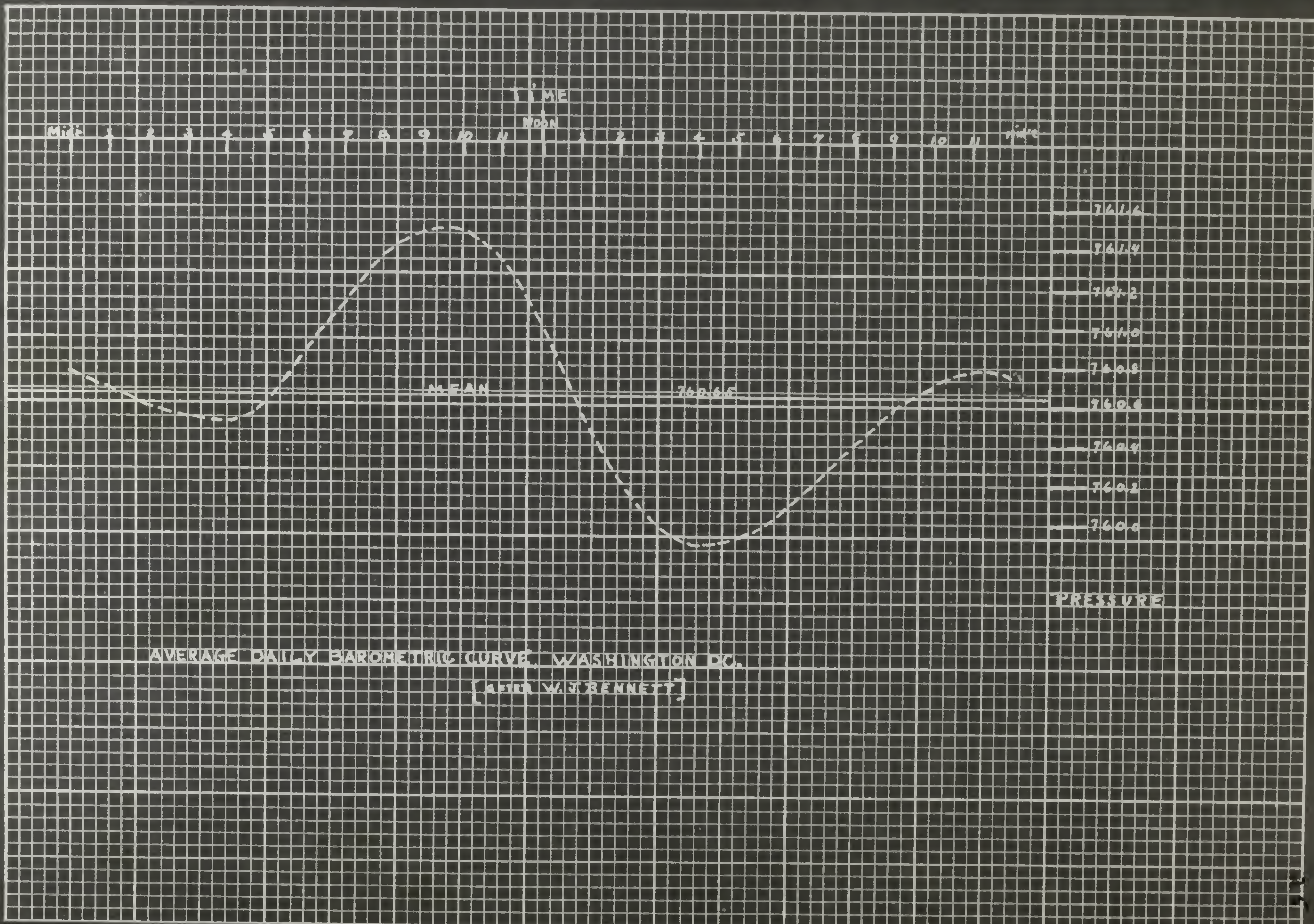
Note.—When using the above maps to correct 3-hour pressure changes, *subtract* algebraically the above values from the corresponding pressure changes reported in the observations. Examples: If a rise of .06 is reported from Key West and the normal change is +.03, subtract +.03 from +.06 and use +.03 for the corrected change; if a rise of .06 is reported from San Francisco and the normal change is −.02, subtract −.02 from +.06 and use +.08 as the corrected change.

in conjunction with the value taken from the normal map for that area.

As an example of this we show an average daily barometric curve for Washington, D. C., which has been taken from Page 232 of Physics of the Air.

These "normal" values must be subtracted algebraically from the reported tendency to eliminate the effect of the diurnal variation of pressure. The result is then the "effective" tendency as defined in Chapter II.

In computations, except for deepening and filling, the effect of diurnal pressure change is eliminated since we are concerned with differences between tendencies in a given area. Thus, the tendencies considered are subject to the same diurnal change and their difference is that due only to the moving pressure system.


TIME
Mid't 1 2 3 4 5 6 7 8 9 10 11 NOON 1 2 3 4 5 6 7 8 9 10 11 Mid't
761.6
761.4
761.2
761.0
760.8
760.6
760.4
760.2
760.0
MEAN 760.65
PRESSURE
AVERAGE DAILY BAROMETRIC CURVE, WASHINGTON D.C.
[AFTER W. J. BENNETT]

VI. DEEPENING AND FILLING

It is frequently desirable to know whether or not a pressure system is changing in intensity, and the rate of this change.

The tendency reported by any fixed station is composed of three effects; the change in pressure due to diurnal variation of pressure at the station, the change due to the movement of a pressure system past the station, and the change due to a change in intensity of the system. So we may write:

$$T_{deepening} = T_{observed} - T_{diurnal} - T_{movement}$$

The tendency due to diurnal variation may be determined by the methods described in Chapter V.

The tendency due to movement of isobars past the station may be determined if we know the velocity of the system of isobars, the direction of its motion and the value of the pressure ascendant of that portion of the pressure system which moved over the station during the tendency time interval.

This value of the pressure ascendant is readily determined by the number, or fraction of unit isobars which have moved over the station during the time interval by measurement on the map. The velocity and direction of movement of the system may be computed by use of the appropriate velocity formula. Knowing these quantities, the tendency due to movement is readily determined. In practice, after having computed the velocity of the center of the system, we lay off a distance equal to a three hour displacement, in the direction of motion, which locates a point. The difference in pressure between the center

and this point measures the tendency due to motion of the system.

These two tendencies (diurnal and movement) subtracted algebraically from the observed tendency give the deepening tendency. The sign will be plus for filling and minus for deepening.

In stationary systems, and those containing weak gradients with slow motion, the tendency due to movement is negligible; in rapidly moving systems, however, this member is the greatest.

The instantaneous effective tendency at the center of a system is the measure of the deepening or filling which is taking place at the center. Therefore, the tendency profile will have a value on its ordinate, drawn thru the center of the system, which is zero only when the center of the system is neither deepening nor filling.

The deepening or filling which is taking place within any closed isobar is determined from the planimetric value of the instantaneous effective tendencies within that isobar.

VII. CONCLUSIONS

As previously mentioned these two series were selected because they are hurricane situations. They do not represent ideal types which present unusually favorable opportunities for computation. In fact, being summer situations, they present a less favorable condition than at other seasons of the year when air mass distinctions are more marked.

The results obtained in the study of these two series would indicate that the application of these methods is practical in the analysis of the daily weather map.

In general, it has been found that velocity computations give excellent results, which, when extrapolated for twelve hour periods, give displacements which compare very favorably with actual displacements. Extrapolation for larger periods magnifies any error of computation and disregards any change in conditions of that system or surrounding systems which may influence the computed instantaneous velocity.

Having computed the velocity of a system, in extrapolating the movement, it is necessary to consider the effects and movements of surrounding systems, therefore, while application of formulae is mechanical, judgment is necessary in applying the results. One should expect, then, to get more accurate results with experience.

In many cases, computations are not practical or not desirable, but the methods and principles of this system may be applied in a qualitative manner as we have attempted in the study of these two series. This analytical method

should augment the ordinary methods of analysis.

The development of the approximate formula for velocity in the discussion of Map M is an example of applying the principles of the method and is an extension of its use. This illustrates the adaptability of the formulae to special situations where reasonable assumptions can be made.

The rapidity and ease with which the Frontal velocity formula can be applied make it especially adaptable for use on the daily weather map. No construction lines need be drawn and computations can be made mentally. One is able to rapidly determine the displacement of the Front by merely multiplying the differences in tendencies at the point of computation by four tenths, multiplying the distance h by this number and laying off this distance along the positive direction of the straight portion of the isobar which was decided on as lying along the axis of computation. The point thus obtained represents the 12 hour displacement.

For short time intervals, say 12 hours, the instantaneous velocity extrapolated agrees closely with the observed displacement. With acceleration forces present, longer periods of course have greater errors and acceleration must be taken into account by one of three ways, namely:

1. Comparison of past displacements with displacement computed from present instantaneous velocity.

2. By consideration of the curvature of the tendency profile in accordance with rules 13 and 14 and the applications of rules 15, 16, 18 and 19.

3. By computation of acceleration using the best available information.

In the latter case, the accuracy of the computation will depend on the adequacy of reports, the judgment in drawing isobars and isallobars and in interpolating between those drawn.

The first two ways must be considered as qualitative. They really give us little more than the sign of the change taking place. This is, of course, an assistance.

Several computations of accelerations are included in these series, in addition, a number of similar computations were made which are not included. In attempting to determine the practicability of acceleration computations, the use of the six hour airways reports was investigated in conjunction with the daily weather map. These computations were carried on for several weeks, using the two A.M. airways reports as received at the East Boston Airport and the 8 A.M. daily weather map. The computations in this investigation proved highly unsatisfactory, due primarily to the fact that the network of two A.M. reports is inadequate and that of this network there are relatively few which are in common with the Weather Bureau network.

The various computations of accelerations which have been made indicate that the results are unreliable, and that their use, even with accurate information available, is impractical with the present network of stations in the United States.

The calculation of deepening and filling may be made on the daily weather map with good results. Consideration of the diurnal variation in pressure is a factor which might very easily

be overlooked. It is hoped that this paper emphasizes the importance of this consideration.

Computations of occluding velocities demand that the assumptions of isobaric symmetry maintain. In instances where such is not the case, qualitative information may be obtained by use of rules 33, 34 and 35.

The above remarks refer to conclusions drawn regarding the utility of various computations on an ordinary daily map.

Specifically, these series show the application of these methods in hurricane situations. As a result of this application, it can be said that these hurricanes obeyed rules one and two. That is, they moved in the directions of their isallobaric gradients. In consequence of their adherence to this rule, we can say that they definitely showed their direction of motion and changes of this direction. By observing the isallobaric gradient through the use of continuous tendency reports we were able to determine the directions of motion of the Hurricanes, note their changes of courses by the movements of these gradients and predict those points on the coast where the hurricanes would first arrive.

In the first series we had a flat and stagnant general pressure condition and the hurricane came inland, in the second series, with rapid movement of pressure systems from West to East, the hurricane did not come inland. Inasmuch as there was no particular activity along the Atlantic Coast in either case, we must assume that the paths followed by the hurricanes were the results of the general pressure movements. On the basis of

these two particular series, it appears that there is a definite correlation between the path of the hurricane and the general movement of the pressure systems. Positive conclusion as to this correlation can be made only after the analysis of additional hurricane situations.

Application of these methods to the pressure field of the hurricane gave uniformly good results, with the exception of acceleration computations. Therefore it can be said that a hurricane behaves in a manner similar to any other low pressure system as far as this method is concerned, at least, after it reaches the latitude in which we were able to work.

These conclusions are based solely on a consideration of pressure distributions and it is realized that other factors, such as temperature and specific humidity distributions play an important rôle. Therefore these remarks concern only one phase of the entire problem.

In closing these remarks, it is believed that an increase in the usefulness of these methods would be obtained if the following were available on the daily map.

1. Tendency reports to the nearest hundredths, including the zero report.

2. The two consecutive tendency reports on each map. This information would be useful analytically, would increase the information to be obtained from tendency characteristics and would permit of daily acceleration computations which might demonstrate their practical application.

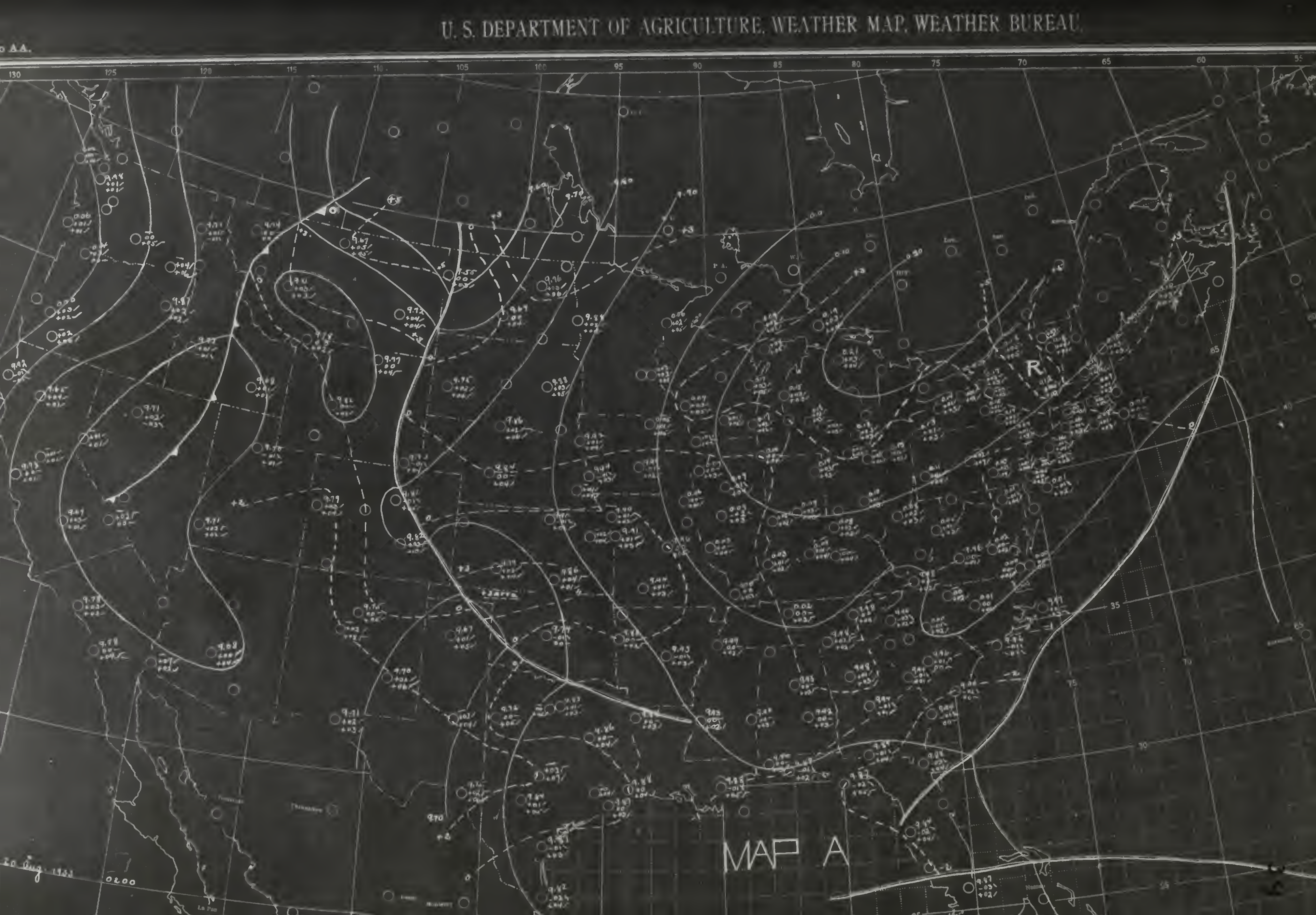
VIII. Pressure System over the United States 20-25 August 1933.

There follows a detailed analysis, with reproductions of the original maps.

Following the last map is a plot showing computed and actual positions of the Hurricane.

The make up of the maps is described in Chapter I.

On certain maps an auxiliary axis has been drawn in order to avoid congestion. This axis is merely a projection of the axis of the hurricane, and shows the centers of isallobaric highs and lows relative to the original axis.


U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.
MAP A
R
0200

MAP B

On inspecting the map of 0800, 20 August, we see that the long axis of the High runs approximately from A to B as indicated, and that the tendencies for the past 3 hours are between +2 and +4 along the axis, northeastward from about the 29.90 isobar. On inspection of the A. M. normal pressure change for this area, we see that it is +2. This would indicate a filling of the High at a very slow rate, since the tendency along the wedge line, corrected for diurnal range, is a direct measure of the deepening or filling. This slight filling can be verified on the 0800, 21 August map, both maps, of course being subject to the same diurnal tendency values for the previous three hours.

In order to compute the rotation of the axis of a pressure system, it is necessary to compute the velocity of two or more points along the wedge and determine the angle of rotation by subtracting one from the other, the difference being the tangential velocity of a vector drawn from the center of the system. In this case it can be seen at a glance that the tendencies run, in general, perpendicular to the wedge line. This means that the numerator of the formula for velocity must be zero, since there is no difference in tendencies between $(\frac{1}{2},0)$ and $(-\frac{1}{2},0)$, the X axis being drawn perpendicular to the wedge line. This means that the velocity of the wedge is zero, all along, i.e., no translation and no rotation. This seems to agree with the succeeding maps. It will also be observed that the tendencies for the previous three hours are roughly parallel and about .01 inch higher than those for the preceding three hours. When we consider that the diurnal

range is fairly flat from 11 P.M., to 5 A.M., then rises .02 from 0500 to 0800, we conclude that the tendencies due to filling are substantially equal for the two three hour periods. This indicates that Δ T is zero along an X axis perpendicular to the wedge, and by inspection of the acceleration formula, it will be seen that the numerator will come out to be zero again. This means that accelerations as well as velocities of the wedge are zero, so there is no reason to expect motion along an axis perpendicular to the wedge. Drawing this short axis from C to D we find a very similar condition as regards filling, velocities and accelerations. Our conclusion is that the High pressure area will remain in about the same position with little change in intensity or change of form for at least the next 24 hours.

Let us now compute the velocity of the front which runs from Williston, North Dakota, through Vicksburg, Mississippi. Since the isobar's gradient is very slight, for convenience, we will use the trough formula as an approximation of the movement of this front. Drawing as an X axis the line E F we lay off the unit distances (0,0),(1,0)(-1,0) etc., as indicated. Using the formula

$$C_T = -\frac{T_{(\frac{1}{2},0)} - T_{(-\frac{1}{2},0)}}{P_{(1,0)} - 2P_{(0,0)} + P_{(-1,0)}}$$

we get

$$C_T = -\frac{0 - (+2)}{29.90 - 2(29.78) + 29.84} = +\frac{1}{10} \text{ unit in three hours}$$

These values are marked on the chart as they are picked off the

pressure field.

The same procedure is carried out along axis G to H getting

$$C_T = \frac{0.5 - (+3)}{29.98 - 2(29.80) + 29.80} = \frac{2.5}{18} = .14 \text{ unit in 3 hours}$$

ACCELERATIONS.

Along axis E F

Using formula for approximate acceleration

$$A = -\frac{P_{102} \quad P_{200} - 2P_{101} \quad P_{201}}{P^2_{200}} ; \qquad \Delta T = T_{now} - T \text{ 3 hrs. previous}$$

$$= -\frac{[\Delta T_{(\frac{1}{2},0)} - \Delta T_{(-\frac{1}{2},0)}]\,(P_{(1,0)} - 2P_{0,0} + P_{-1,0}) - 2[(T_{\frac{1}{2},0} - T_{-\frac{1}{2},0})\,(T_{1,0} - 2T_{0,0} + T_{-1,0})]}{(P_{1,0} - 2P_{0,0} + P_{-1,0})^2}$$

$$= -\frac{[0.5 - (+1)]\,(20) - 2(-2)\,[+0.5 - 0 + 2]}{(400)} = -\frac{-10 + 10}{400} = 0$$

Note that those terms within curved brackets can be taken from the velocity computation.

Along Axis G, H,

$$A = -\frac{[0 - (+1)]\,(18) - 2(-2.5)\,[+2 - 0 + 3]}{(18)^2} = -\frac{-18 + 25}{(18)^2}$$

$$A = -\frac{8}{(18)^2} \approx -\frac{1}{40}$$

Now to determine the position of the front 24 hours hence we use

the Formula

$$S = C_T t + \frac{1}{2} A t^2$$

Along line E F, since A = 0, we get $S = \frac{1}{10} \times 8 = \frac{8}{10}$ unit

(8 = number of 3 hour time periods in 24 hours).

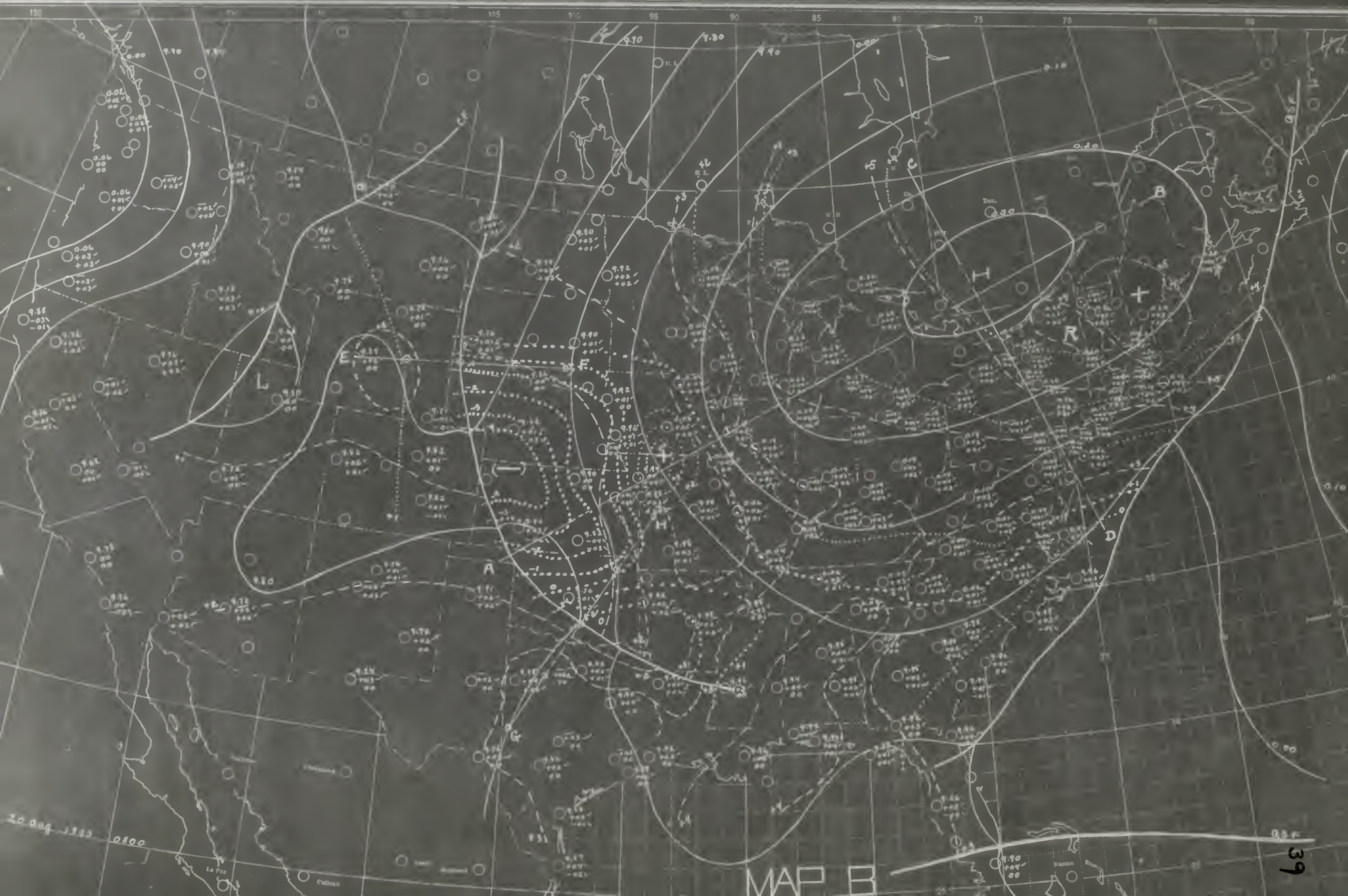
Comparing this computed movement with that actually observed in 24 hours we get close agreement.

Along line G H, in 24 hours

$$S = .14 \times 8 + \left(\frac{1}{2}\right)\left(-\frac{1}{40}\right)(8)^2 = 1.12 - \frac{64}{80} = 1.12 - .8 = .32 \text{ unit}$$

Comparing this with the observed displacement we see that the computed displacement is somewhat less than actually took place. The acceleration, however is in the correct direction. It will be seen from the above examples of accelerations that the ΔT terms are most important in the formula. It may also be observed that these values are the most difficult to determine because of the irregular character of the isallobars. It is for these reasons that computation of accelerations is not particularly practicable on the weather map.

U. S. DEPARTMENT OF AGRICULTURE WEATHER MAP. WEATHER BUREAU.



MAP C

Considering the front from Salt Lake City around Yellowstone, we observe an area of generally negative tendencies to the southeast of the front and a similar rising area on the other side of the front. In the Rocky Mountain region where atmospheric pressures are corrected to sea level pressure for entry, we should remember that these pressures are fictitious and do not represent the actual pressure system on the surface. Therefore, if we try to make computations of velocities in this region, those pressures we pick from the map will give erroneous results because of their fictitious character. It will be noted that temperature plays an important rôle in the reduction to sea level pressures, so that the isobars we draw in on the surface map over this region are the resultant of pressure and temperature changes, rather than pure pressure changes. Therefore, these isobars are not applicable to our formulae which are derived from considerations of pressure only. But, although reduced pressures are fictitious, pressure tendencies are real, just as they are for sea level stations, so we can consider these tendencies and draw general conclusions, even though we are unable to make computations.

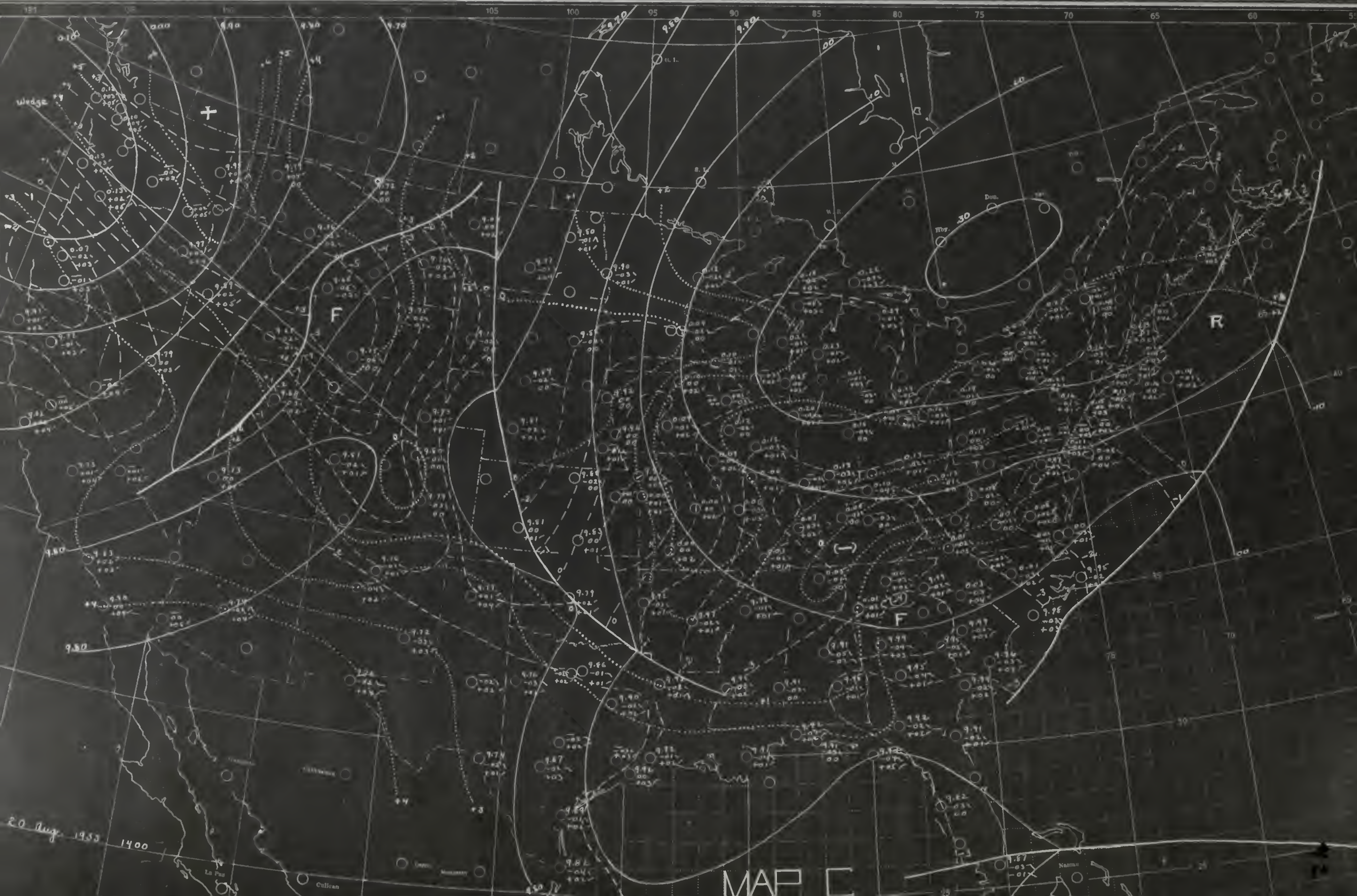
This isallobaric gradient which we have observed will have the effect of giving a large value of velocity in the velocity formula, so, in general, we should expect a rather rapid movement of this front to the southeastward. This will be accompanied by a slight increase in the High pressure area centered about Tatoosh Island because in the wedge we observe + 3 and + 4 tendencies. These two observations are in agreement, as we would expect the High to fill in over Northwestern United States, while at the same

time the frontal surface advances before it.

In general, this map has changed little from the preceding map; the entire U. S. area is characterized by practically stationary pressure systems which are changing in intensity only slightly.

Map AA.

U.S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.



MAP D

The most significant feature of the map of 20 August, 2000, is the fact that the zero isallobar for the past three hours lies in approximately that position indicated as zero normal pressure change in the diurnal pressure change chart. This indicates, of course, a steady condition for a stationary system, the pressure system neither filling nor deepening, and it will be noticed that the long axis of the High lies along the same general line.

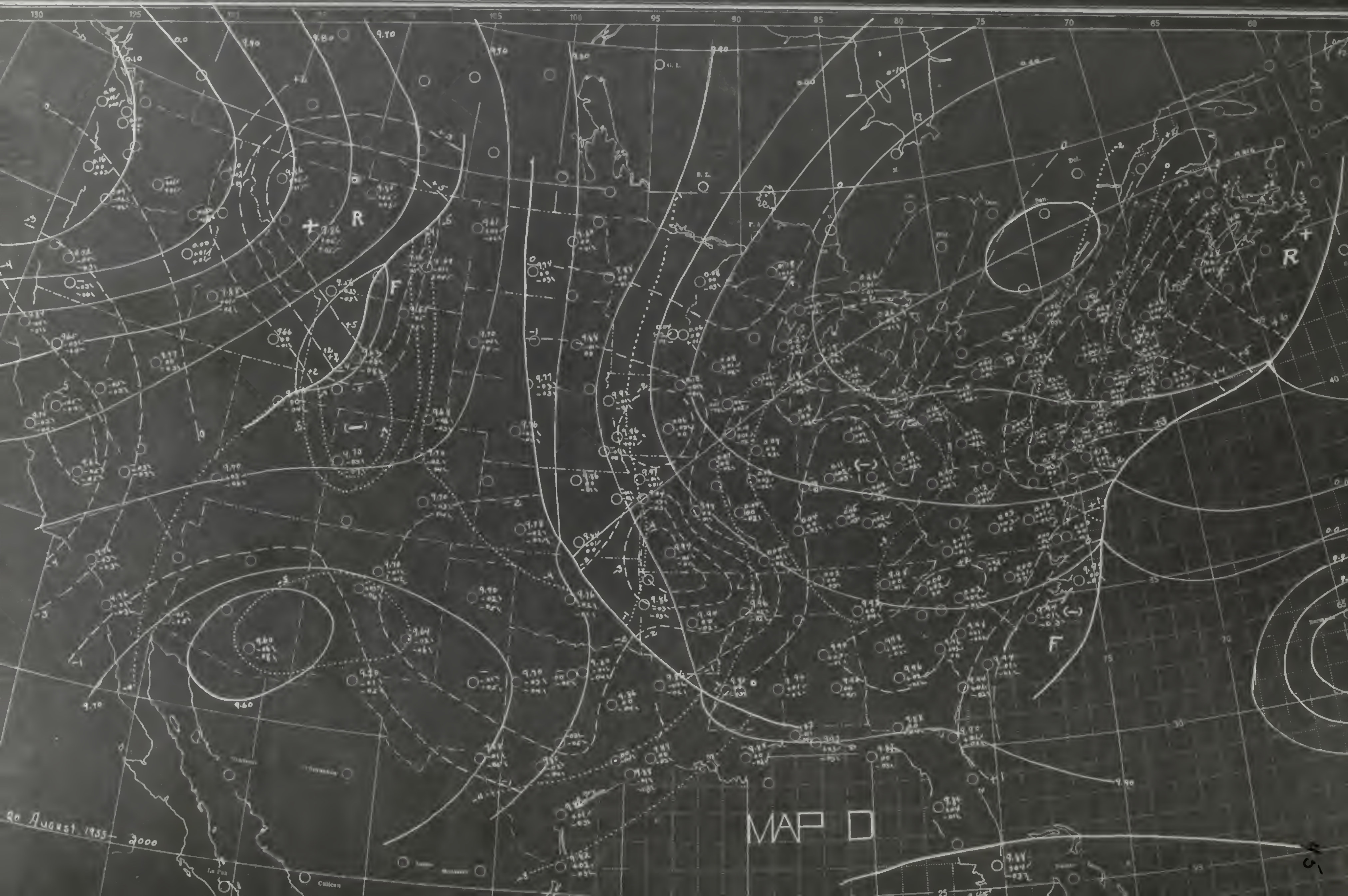
The front in the Rocky Mountain region continues to experience a rapid fall in tendencies in advance of and rise behind it and we can see that its motion is correspondingly rapid.

The approaching hurricane is first observed on the map at this point. Assuming its course as unknown, and noting that the tendencies over the High pressure area are very slight and indicate a zero change, if we consider the diurnal range, there can be no resistance to the movement of the pressure system surrounding the hurricane due to a building up of pressure anywhere in the Southeastern United States. Tendencies in Southern Florida have the normal value for 8 P.M., but the tendencies along the Carolinas are recorded as zero and plus one whereas for this region the normal change is plus 2, we therefore have a falling pressure; this is accentuated in the area surrounding Norfolk. This station observes a minus two which indicates an actual minus four. On the continent we might expect the area of least resistance to be along the North Carolina Coast, because of the foregoing reasons and the fact that there is a concentrated rise in the isallobaric system along the northern Atlantic Coast. As observed before, Southern Florida is maintaining its pressure level and this area along the

Carolinas is the weak area in the Atlantic pressure system. Had there been rising tendencies all along the Atlantic Coast, we should have expected that the hurricane would have met resistance which would have prevented its coming inland. But we observe this weak area and with the lack of observations over the sea region, we might expect the approach of the hurricane towards the region of falling pressure.

Map A.A.

U. S. DEPARTMENT OF AGRICULTURE WEATHER MAP, WEATHER BUREAU.



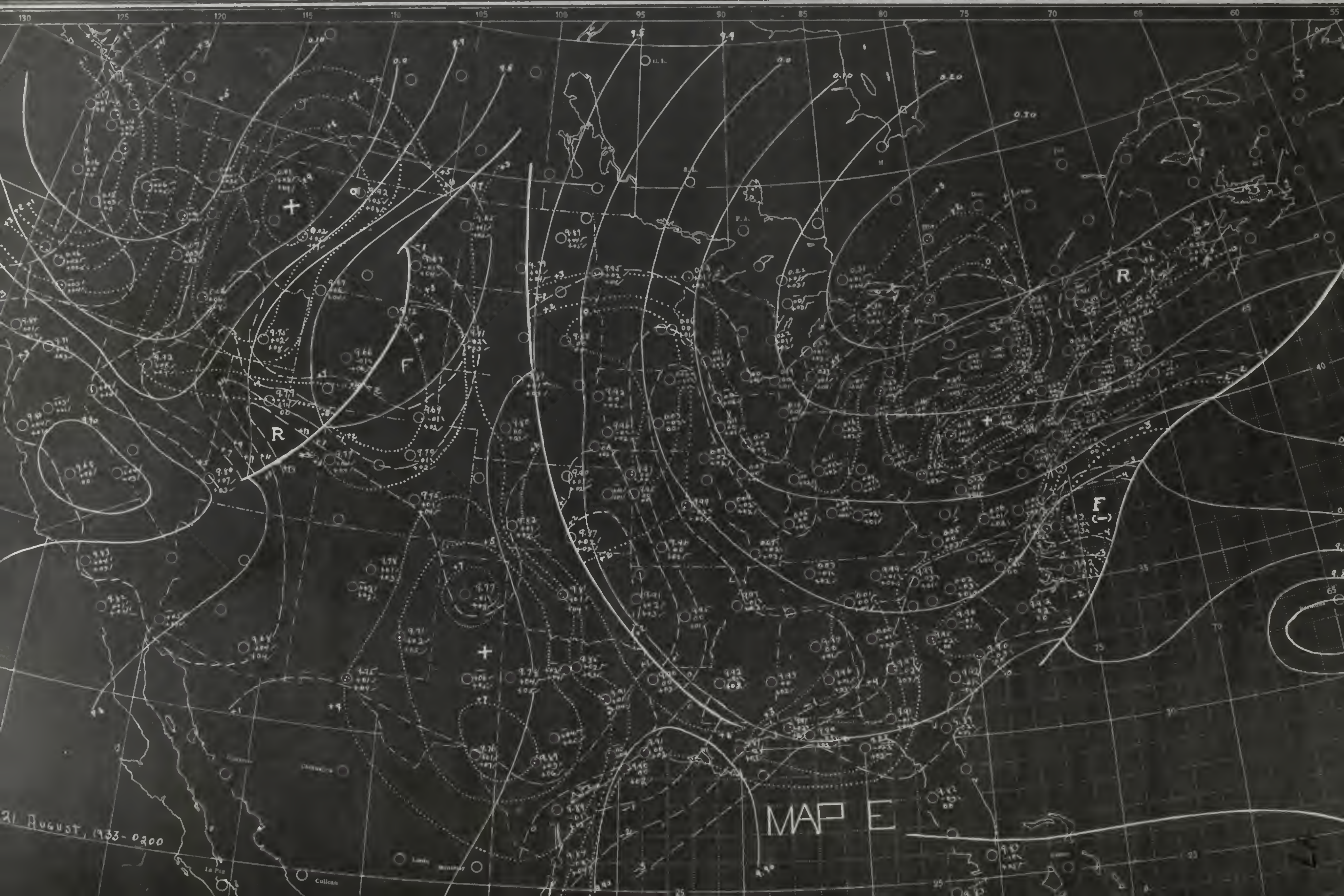
MAP E

This map shows continued falling tendencies along the East Coast, indicative of the approach of a low pressure system. Bearing in mind the diurnal range, at 0200, these tendencies observed are about the corrected tendencies. The entire East Coast is subject to minus tendencies, with a marked center for the falls for the two tendency periods about Norfolk, Virginia. Due to lack of observing stations in the ocean area, computations can not be made, but these falling tendencies would indicate a movement of the old front lying along the coast in a westward direction. This movement of the front towards the area of falling tendencies was actually observed on the regular map from hydrometeors and ship reports, and lay in position indicated in later maps. Note that the concentrated area of rising tendencies along the Northern Atlantic Coast, remarked on in the preceding map, has resulted in an elongation of the High pressure system and a corresponding displacement of the old front along the Atlantic Coast to the eastward.

The general situation over the continent is unchanged, the stagnant High filling very slowly as before, with no indication of movement by consideration of tendencies. The western fronts continue as before.

The Hurricane continues to move in a general westerly direction, parallel to the isobars and the only indication on the map of its approach to the continent is the condition for retreat of the old front, that is, falling tendencies to the westward of the front.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.



MAP F

The Atlantic Coast front, in its southern section has moved westward to the Carolina Coast and it appears from the regular surface map that the air mass differences are becoming very indistinct. The northern portion of the same front continues its motion in a southeasterly direction. It appears that this front is now tending to take up an East West position, that is, it is rotating with the pivot point about where the front crosses the 70° longitude line. This motion is in agreement with the general effectively falling tendencies along the central Atlantic seaboard.

We will apply the term "effective" tendency to the tendency which is obtained from the observed tendency after it has been corrected for the diurnal tendency for the same three-hour period as taken from the Normal Pressure Change maps or normal diurnal curve.

It is important to notice that the effective tendencies along the Carolinas continue to be slightly negative. The plus 02 dashed isallobar becomes effectively minus one, while the minus 01, dotted isallobar, represents the effective tendency for its 3 hour period (see normal diurnal curve). These two minus 01 isallobars run roughly coincident. This means that over this region we have had a steady rate of fall of .01 inch every three hours. This represents a steady condition, that is, no accelerations have taken place, therefore we should expect this rate to continue for some time. In twenty-four hours, eight tendency periods, we would

get a deepening of 8 x .01 = .08 inch. Comparing pressures at Jacksonville, Charleston, Savannah, and Wilmington at 0800 on 21 and 22 August, we see that the pressures observed 24 hours later are in close agreement with this rate. This is an example of the usefulness of double tendency reports even where the acceleration formula can not be directly applied but where its principles may be utilized.

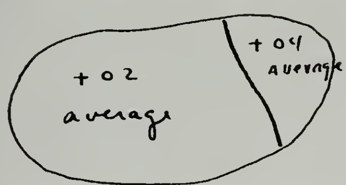
Map A.A.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP G

The dashed minus 03 tendencies located in the center of the stationary high give an effective zero pressure change. Within a closed isobar, the expansion or contraction of the closed curve (i.e., deepening or filling) is measured by the planimetric value of the enclosed tendencies. In computing this value we know that the deepening is a function of the product of the tendencies and their area, divided by the entire area.

Roughly, as an example, say that the plus 04 area is only 1/6 that of the area within the curve. The value then is



$$\frac{2 \times 5 + 4 \times 1}{6} = \frac{14}{6} = 2.3$$

On this map we do not have all the information within the isobar, nor the complete curve, but we can see by the shape of the minus 03 isallobar that the general value within the isobar may be approximated as between minus 02 and minus 03. This gives an effective tendency of about zero.

Therefore we should expect the 0.30 isobar to remain stationary.

The wedge line shows an effective zero tendency and the High pressure system continues to remain stationary and unchanged.

The effective tendencies along the Carolinas continue to be minus 01.

Map A.A.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP H

When we consider this map the most noticeable feature is the general area of falling tendencies east of the Middle States' Front. We see that the Appalachian region alone does not report actual falling tendencies. These are rather uniformly plus 01. Now if we compare this map with the Normal Pressure Change Map for that period we see that our isallobars arrange themselves very well in the same general distribution as shown thereon; however, we note that when we correct our reported tendencies for the normal change, we find that we have an effective fall of 02 in the entire area east of the Appalachians, and extending up to the St. Lawrence River. This minus 02 area indicates additional falling tendencies compared to our previous minus 01 along the Atlantic Coast. It is to be noticed that the isallobars are arranging themselves parallel to the Atlantic Coast. This means that the falling tendencies are general with no particular area of rising tendencies which might act as a resistance to the motion of the hurricane, but there is, as yet, no point of particular weakening in the isallobaric system which might indicate the direction of motion of the hurricane.

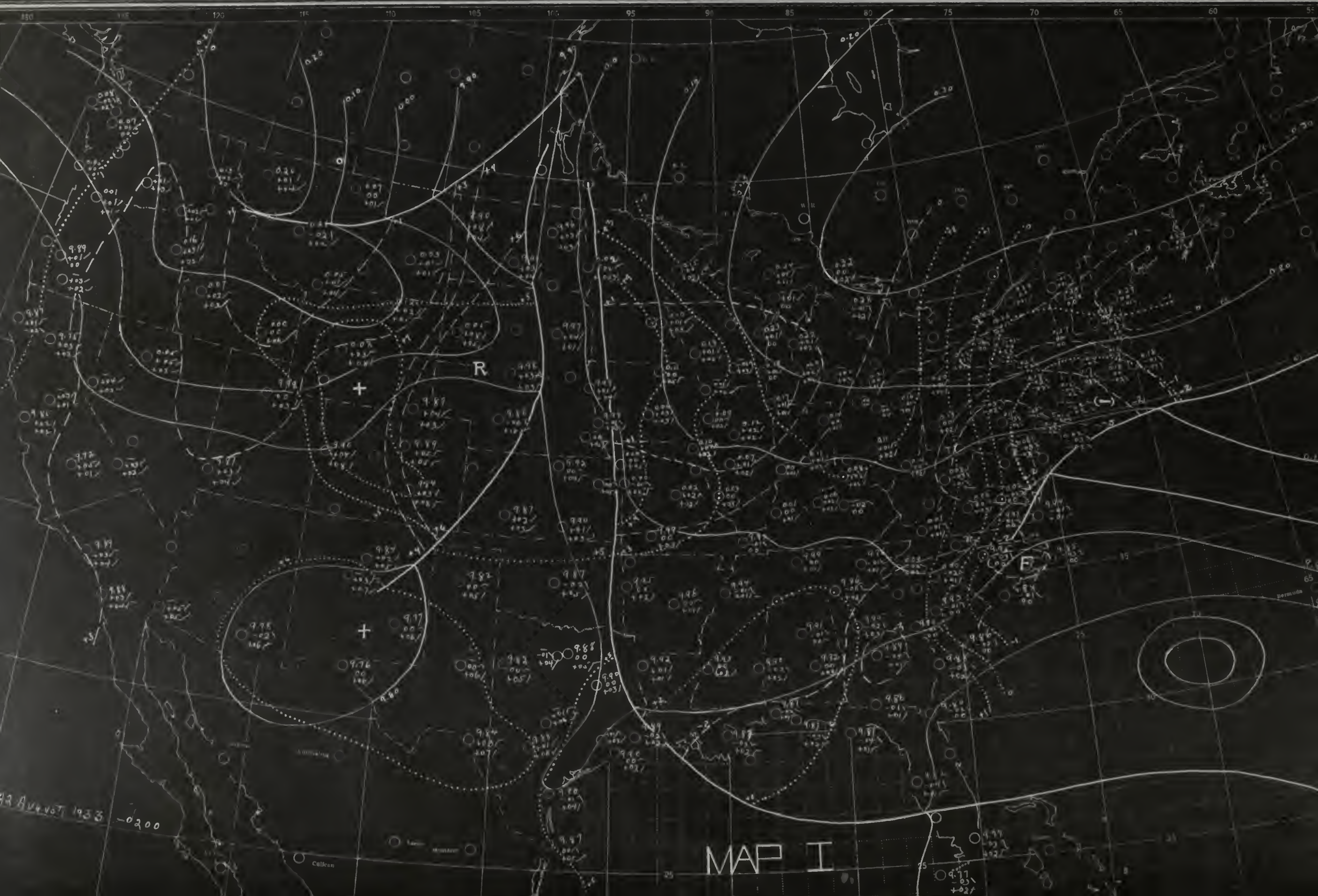
U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP I

This map shows continued minus 02 tendencies along the Atlantic seaboard with possibly greater falls at Hatteras and Raleigh and over Maryland, New Jersey and Southeastern Pennsylvania. The large High centered over the St. Lawrence valley continues to change little in either shape or intensity; tendency values along the wedge continue to indicate a stagnant condition.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.



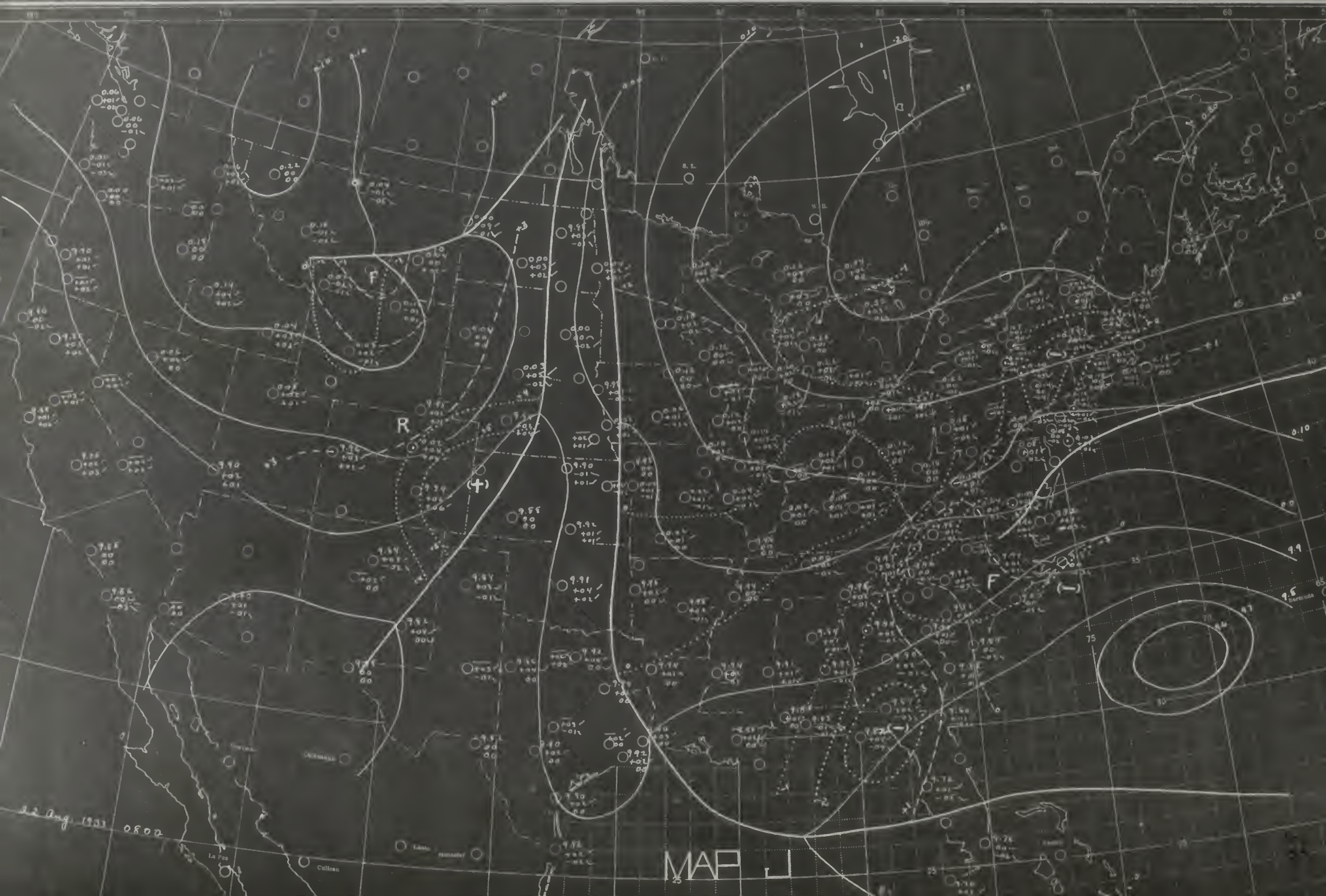
MAP J

The plus 01 dashed isallobar includes the Eastern seaboard as far west as the Appalachians, and as far north as Block Island. This indicates an effective minus 02 tendency over this region and in addition we observe zero tendency reported at Charleston, Wilmington and Hatteras which indicates an effective minus 03. The dotted minus 03 isallobar, which is the effective tendency for the period, includes the same area as that of the dashed effective minus 03 isallobar. It will now be seen that for nine hours the effective tendency has been minus 03 over this area. Therefore it can be said that this area constitutes the region of greatest weakness along the Atlantic Coast.

From the beginning of the series we have seen that falling tendencies were prevalent over Eastern United States and especially along the Atlantic Coast. We have now found a definite point of weakness along the coast. It is reasonable to expect that the approaching hurricane will not be repulsed by the stagnant slightly falling pressure system over the continent and if it comes inland, will do so at the point of greatest pressure fall. In other words, if the hurricane behaves in the manner of any other low pressure system, we would predict its motion to be towards this point of falling pressure, having no contrary evidence of any kind.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.



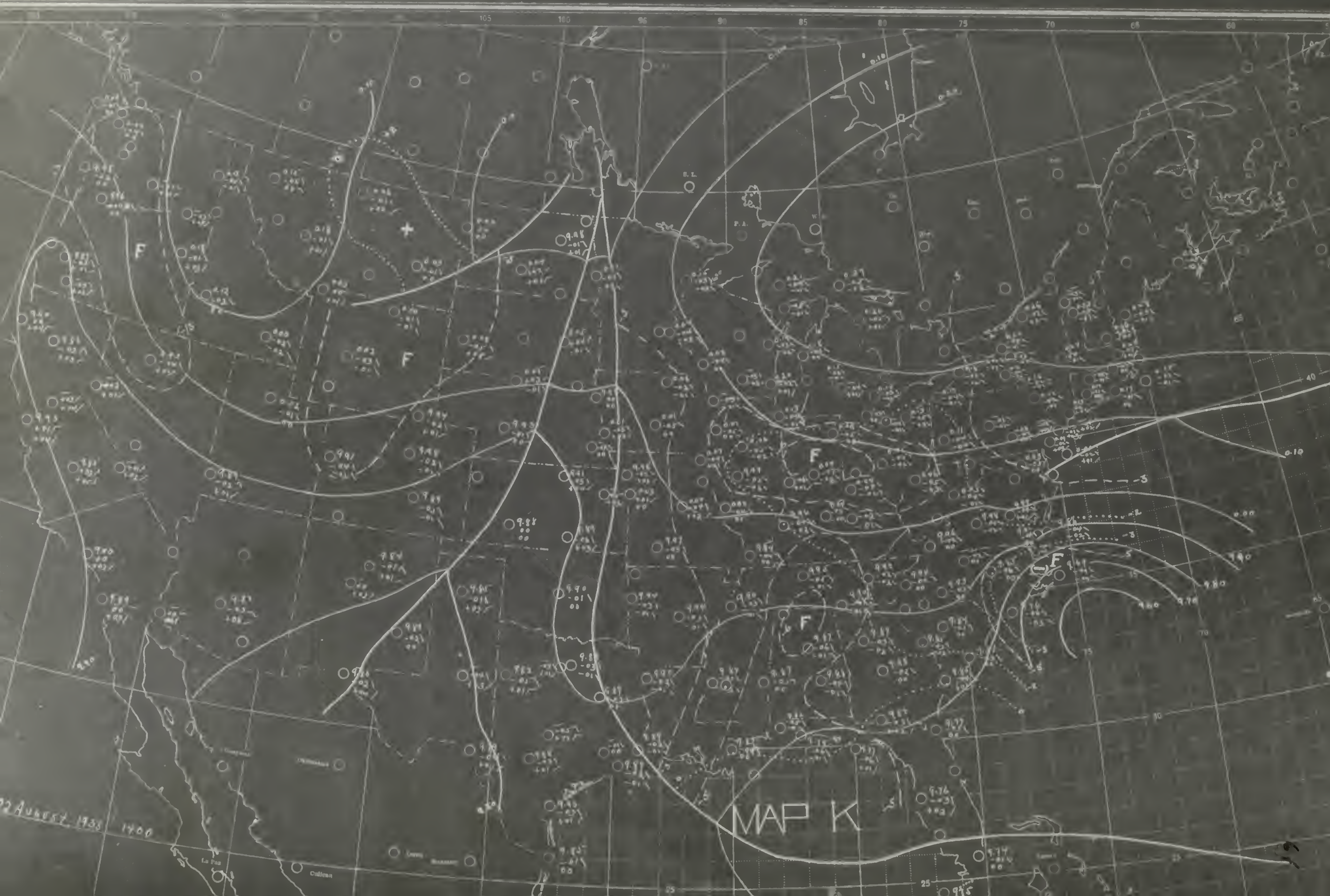
MAP K.

We come to the 1400 map. The three hour (dashed) isallobars indicate the pressure changes from 11 A.M. to 2 P.M. This is the period of maximum fall during the day at these coastal stations, and the magnitude is approximately minus 03. See the curve of diurnal range. Dashed minus 03 lines are therefore lines of effective zero tendencies. The South Carolina, Georgia, Florida coast shows an effective zero, but when we consider the coast to the northward we again see the effective minus 03 area, which has persisted in the same region for each tendency period for the past twelve hours and in addition we see that Hatteras now reports an effective minus 06. This decided increase in the rate of fall following the steady rate of fall for the previous periods would seem to indicate an accelerated transport of lower and lower isobars across that station. If we assume circular isobars in the approach-low pressure system, we would expect its motion to agree with Rule No. 1, namely, "Circular centers of lows move along the isallobaric gradient." Hence we can say that since the transport of isobars across Hatteras is greater than at any other station, and since Hatteras lies within the area of greatest falling tendencies along the coast, we are justified in expecting at this time that the low pressure center will pass in the vicinity of Hatteras. At the same time we notice that over the Great Lakes region, the stagnant high has at least an effective

minus 02 value along the wedge. If we take the normal tendency for this area for this period as between minus 02 and minus 03, we see that the effective tendency is at least minus 02. If this rate continues for another twenty-four hours, or eight tendency periods, these stations should show a decrease in pressure of at least sixteen hundredths. Going to the 1400 map of 23 August we see that the actual decrease in this area was between 17 and 20 hundredths. This is an increase in the rate of weakening or breaking down of the High Pressure system. Since before this time it has offered no resistance to the approach of a low pressure system and now its rate of deepening has increased, the entire system being flat, it follows that the motion of the Hurricane will not be suddenly influenced by the presence of this High pressure system.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.



MAP L.

First to be noticed on this map is an effective minus 18 at Hatteras. A low pressure system is now definitely seen moving on to the Coastal stations in this area. Let us now consider the behavior of the pressure at the individual stations in the vicinity of Cape Hatteras. From our previous chart Wilmington has recorded an effective minus 03, on this map we see that between 1400 and 1700 Wilmington had an effective minus 05, and for the period 1700-2000 an effective minus 08. Charleston at 1400 on Map K the effective tendency was zero, from 1400 to 1700 it was minus 05 and from 1700 to 2000 it was minus 05. At Norfolk at 1400 we observed an effective minus 01, from 1400 to 1700 an effective minus 05 and from 1700 to 2000 an effective minus 08. Richmond at 1400 was effectively minus 01, 1400-1700 minus 04, 1700 to 2000 minus 05.

Tabulating:

	1400	1700	2000	
Wilmington	-03	-05	-08	increase in rate of fall.
Charleston	0	-05	-05	rate of fall has steadied.
Norfolk	-01	-05	-08	increase in rate of fall.
Richmond	-01	-04	-05	Rate of fall has ~~almost~~ slow ~~steadied~~ increase.
Raleigh	-03	-04	00	Stopped falling.

From a consideration of these values and the isallobaric system shown on the map, it is evident that the Hurricane must move in a general northwesterly direction. This because the pressures on the coast to the south of the Hurricane have effectively stopped falling and the low pressure system must

move along the isallobaric gradient. The fact that along the Coast to the north of the Hurricane effective tendencies continue to be negative, bears out this conclusion.

Map A.A.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP M.

Here we observe the approach of the Hurricane in the same northwesterly direction, following the isallobaric gradient. On this map we can see more decidedly that this gradient is in the Northwesterly direction with Norfolk and Cape Henry showing effective minus 24 tendencies compared to Wilmington which has only a minus 10. In addition Richmond shows an effective minus 12. Hatteras, Norfolk and Richmond are in a line showing the greatest pressure falls and accordingly we now expect the center to follow this line. On this map, for the first time in the series, we can definitely predict the direction of motion of the hurricane. Now let us see if we can get some rough estimate of its velocity. We have no data over the sea, but from the curvature of the isobars we can see that Hatteras is nearest the center of the system. In order to arrive at this estimate from the data available, we will make the following assumptions:

1. Steady velocity.
2. Symmetry of isobars.
3. Symmetry of isallobars.

In making these assumptions we realize that the accuracy of the result depends on how closely real conditions approximate those assumed. In a circular pressure system the assumptions of symmetry are logical and our results will only be extrapolated for 12 hours which will minimize the error caused by the first assumption.

By inspection of the pressure system we see that the tendency and pressure profiles show a fairly constant slope along the line AB from Hatteras to the 29.80 isobar. Hence we will select this distance as our unit = CD. In all computations, positive directions are taken in the sense of the usual XY coordinates, unless specifically stated otherwise.

Knowing that Hatteras is nearest the center of the system and having no better information available, we will take the pressure recorded at Hatteras as that of the center of the system.

Taking the formula for velocity of a pressure system

$$C_L = -\frac{T_{\frac{1}{2},0} - T_{-\frac{1}{2},0}}{P_{1,0} - 2P_{0,0} + P_{-1,0}},$$

we will rearrange the terms in accordance with assumptions 2 and 3, getting

$$C_L = -\frac{2(T_{\frac{1}{2},0})}{2P_{1,0} - 2P_{0,0}} = -\frac{T_{\frac{1}{2},0}}{P_{1,0} - P_{0,0}}$$

since

$$T_{\frac{1}{2},0} = -T_{-\frac{1}{2},0}$$

$$P_{1,0} = P_{(-1,0)}$$

from the assumptions.

Filling in the formula we get $C_L = -\frac{-.25}{29.80 - 28.80}$

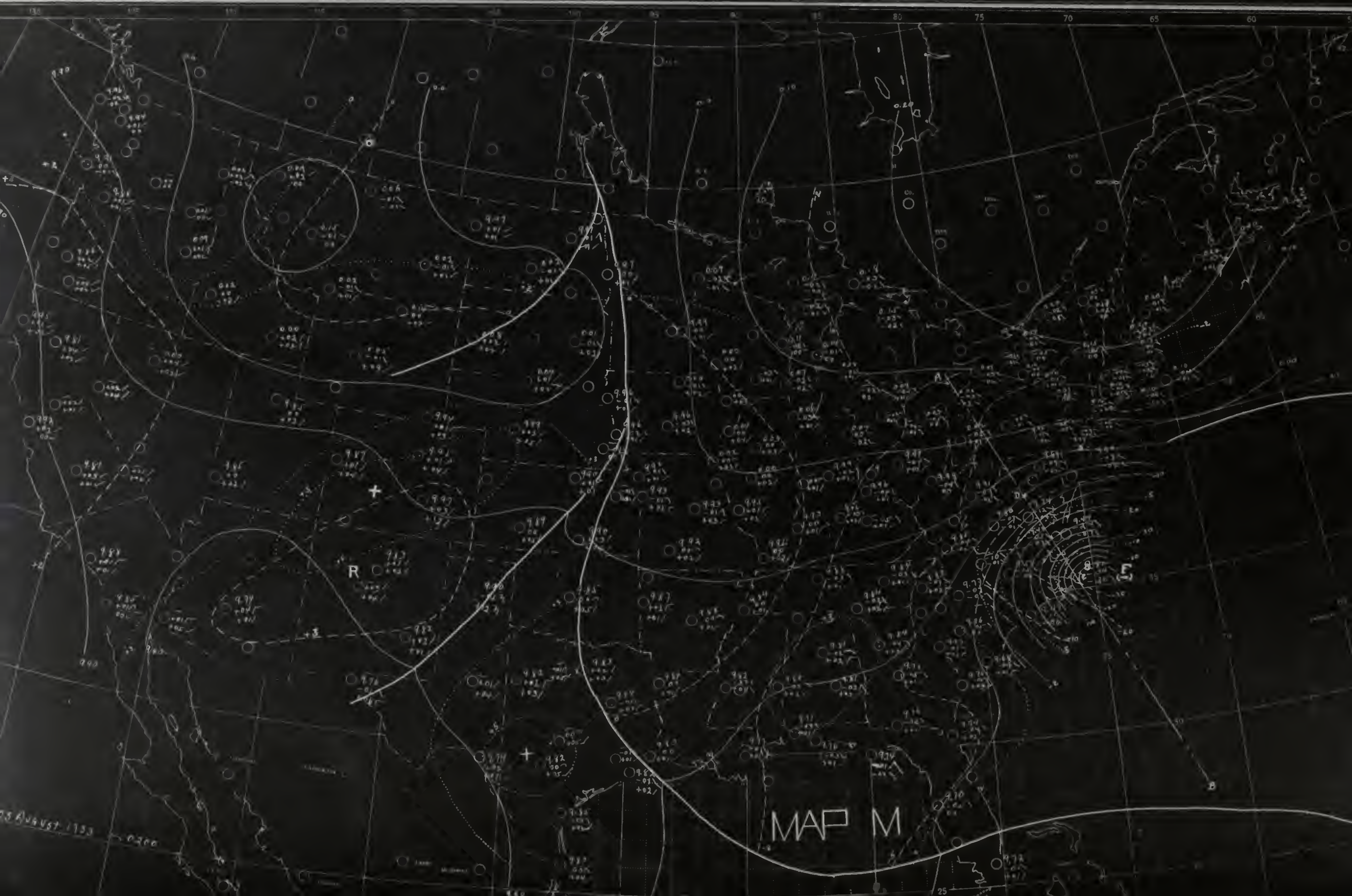
or $C_L = +\frac{1}{4}$ unit.

For a 12 hour displacement we get 4 x 1/4 = 1 unit. This puts the center of the Hurricane just South of Washington, at Point D on 23 August at 1400. Actually we observe on the

map of 1400 23 August that Richmond reports the lowest pressure. Since the center of the low had not yet reached reached Hatteras when we made our calculations, we would expect the center to lie somewhere behind the point of calculation and finding it at Richmond instead of at Point D is in accordance with our expectations. Our rough estimate has proved satisfactory. This is a good example of the utility of these methods for approximation.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE. WEATHER MAP. WEATHER BUREAU.



MAP N.

Drawing the axis AB along the isallobaric gradient we will make another approximation of the velocity. We note the difference in direction between this direction of gradient and that of the preceding map. In this case, however, we have well developed isallobaric systems, On the preceding map we were making our best approximation. In order to make a computation to determine whether this line AB is rotating or not, we draw the perpendicular line EF. It is important to know whether or not the line AB is rotating, because if these is a real and rapid rotation to the right, the Hurricane will change course to the right and pass out to sea again. Using DE as a unit we compute the velocity by the formula

$$C_L = - \frac{\frac{1}{2}\left[T_{1,0} - T_{-1,0}\right]}{P_{1,0} - 2P_{0,0} + P_{-1,0}}$$

we get

$$T_{1,0} = -8$$
$$T_{-1,0} = -8$$

This gives a value of zero for the numerator and our velocity of the Point D towards E is zero.

If we have the velocity of D towards E it is seen that the angular velocity of AB about C can be readily determined. Therefore the line AB is not rotating at this time according to this approximation.

Now we will compute the velocity of the Hurricane along the line of isallobaric gradient AB. Filling in the formula of approximation as in the preceding map we get, for a

unit length of CD

$$C_c = -\frac{T_{\frac{1}{2},0}}{P_{1,0} - P_{0,0}} = -\frac{-27}{29.72 - 28.78} = +\frac{27}{94} = +.29$$

For 12 hours we get a displacement of 4x.29 = 1.16 unit. We have taken Norfolk as the center, actually since pressures are still falling at that station, we would expect the computed center to lie the same distance behind the computed point as the actual center now lies behind Norfolk. The computed point for 12 hour displacement lies just north of Baltimore, this agrees well with the observed position 12 hours later on Map P. It will be remembered that these calculations are still approximate since the pressure system has not come entirely on the continent.

Map A.A.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP O.

By this chart the center of low pressure is definitely on the continent so we can form a fairly accurate idea of the pressure distribution around it. First we draw our expected axis of movement in the direction of the isallobaric gradient, from the isallobaric high to the isallobaric low. This is the line AB. Now we draw the pressure profile along this axis. From this profile we determine the pressure at the center to be about 28.88". Having the pressures and tendencies on both sides of the center along this axis we use the formula:

$$C_L = -\frac{T_{\frac{1}{2},0} - T_{-\frac{1}{2},0}}{P_{1,0} - 2P_{0,0} + P_{-1,0}}$$

to compute the instantaneous velocity, using CD as our unit. Substituting we get:

$$C_L = -\frac{-20-(+23)}{(29.78 + 29.50) - 2(28.88)} = -\frac{-43}{152} = 0.27 \text{ unit}$$

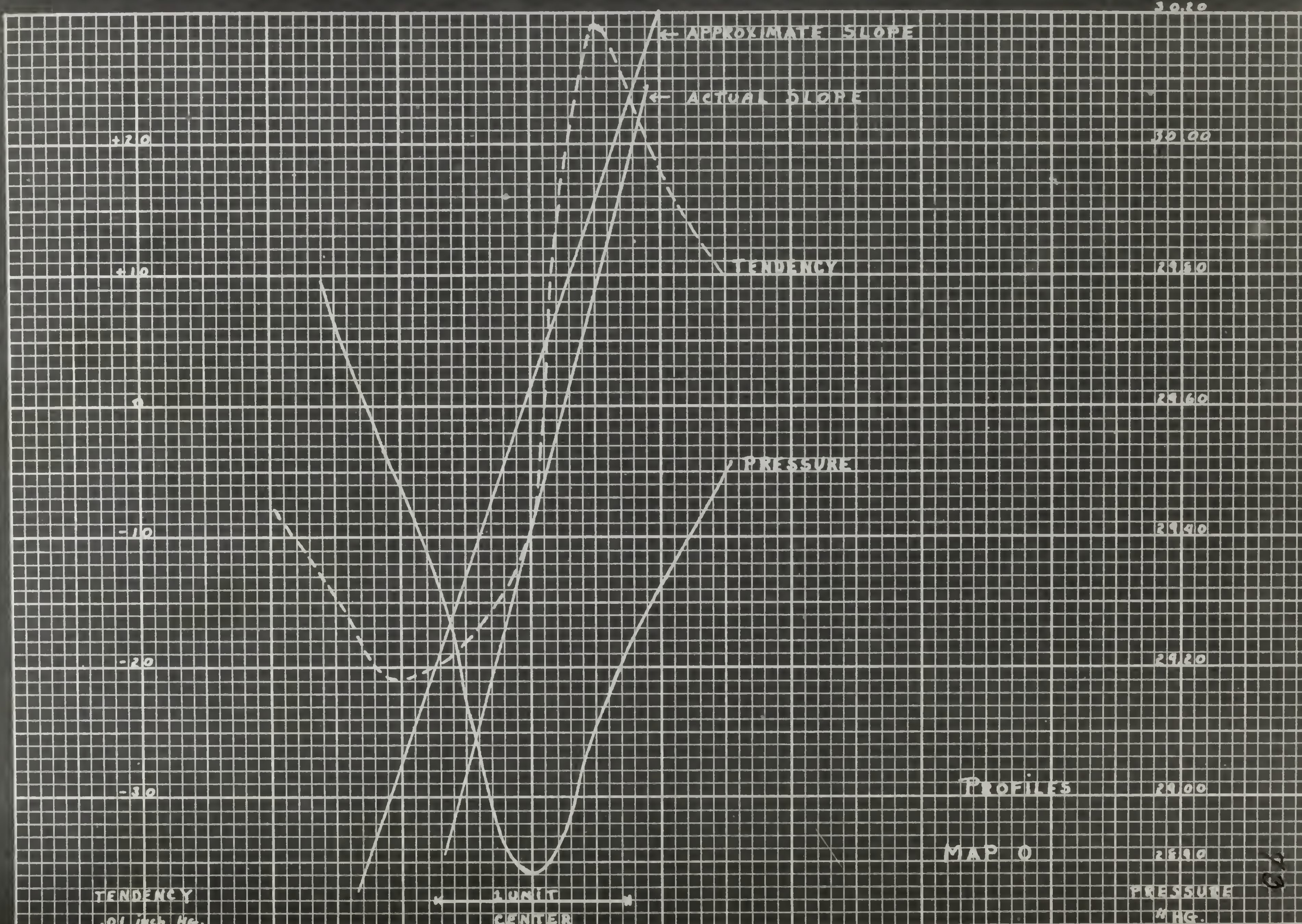
assuming this instantaneous velocity to be maintained for 12 hours we get 4 x 0.27 = 1.08 unit movement in the 12 hours.

This movement places the center very close to Bellefonte. This agrees reasonably well with the actual movement.

Computing the acceleration along the line AB we use as our unit the length CX, more nearly to approximate the true slope of the tending profile.

Our formula is:

$$A_L = -\frac{\frac{1}{2}\left[\Delta T_{1,0} - \Delta T_{-1,0}\right](P_{1,0} - 2P_{0,0} + P_{-1,0}) - (T_{1,0} - T_{-1,0})(T_{1,0} - 2T_{0,0} + T_{-1,0})}{(P_{1,0} - 2P_{0,0} + P_{-1,0})^2}$$



73
← APPROXIMATE SLOPE
← ACTUAL SLOPE
TENDENCY
PRESSURE
PROFILES
MAP O
1 UNIT
CENTER
TENDENCY
.01 inch Hg.
PRESSURE
" HG.
+20
+10
0
-10
-20
-30
30.20
30.00
29.80
29.60
29.40
29.20
29.00
28.80

$$= - \frac{\frac{1}{2}[0-12](71) - (-44)(-20+20+24)}{(71)^2} = - \frac{-(426)+1056}{5041}$$

$$= - \frac{630}{5041} = -.122 \text{ unit per 3 hrs.}$$

This gives us, for the unit length CD,

$$A_L = -\frac{.122}{2} = -.061$$

computing 24 hours displacement,

$$S = \mathbb{C}t + \frac{1}{2}At^2$$

$$S = .27 \times 8 + \frac{(-.06)}{2}64 = 2.16 - 1.92 = .24 \text{ unit.}$$

This result gives entirely too great a retardation, as can be seen from the map 24 hours hence. (See discussion of accelerations in Part I.)

Deepening and Filling.

From Chapter VI of K & DP we take the formula

$$\frac{\delta P}{\delta t} = \frac{\partial P}{\partial t} + \mathbb{C} \cdot \nabla P \ ; \quad \nabla P = \text{Ascendant}$$

This may be expressed also as, (gradient = -ascendant.)

$$T_d = T_o - T_m$$

where

T_d = Tendency due to deepening (or filling). Plus signs indicate filling; minus signs deepening.

T_o = Tendency observed.

T_M = Tendency due to motion.

Having computed $\mathbb{C}$ and knowing the pressure gradient from the isobars drawn on the map, we can enter the tendency values in the above formula and compute the tendency which is due to deepening (or filling) of the system. Knowing T_d we can directly com-

pute the value of the point of lowest pressure on the following map by merely applying the Product of T_d and the number of Tendency periods to the lowest pressure observed on the present map. This assumes a constant rate of filling or deepening. The acceleration or retardation of this rate can be obtained qualitatively by reference to rules 36 and 38, namely, "A cyclone center increases in strength when the tendency profiles are curved cyclonically and decreases in strength when the tendency profiles are curved anticyclonically" and "The increase or decrease in strength is equal to the magnitude of the curvature of the pressure profiles."

We must apply the correction for fiurnal range to the tendency observed in our computations. Taking the formula

$$T_d = T_o - T_M$$

we solve, getting T_o = (-15 Tendency observed at the center) - (-3 correction for diurnal range).

Knowing C we lay off the displacement for one tendency period along the line of motion (AB) with a pair of dividers from C, the center of the system, and observe that in this interval we cross a total of isobars equal to .25 inch of mercury. The point C has then been subject to a dropping tendency of 25 in the past three hours. This then is T_m, the tendency to which the point C has been subject during the period, due to the transport of isobars across it.

Filling in $T_d = T_o - T_M$

we get $T_d = -15 - (-3) - (-25) = +13$

Therefore the center at 2000 on 23 August should be 28.88 (Pressure now) plus 2 x 13 = 29.14

Computed at 2000 = 29.14

Actual lowest press reported = 29.10

Deepest point in pressure trough (see profile) = 29.05

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP P.

Drawing the axis AB along the isallobaric gradient, we see that it lies in the same direction as it did on the previous map, showing no rotation. On inspecting the isallobaric distribution we see that it is now not quite symmetrical with respect to this line, which would lead us to suspect that there is going to be a rotation set up.

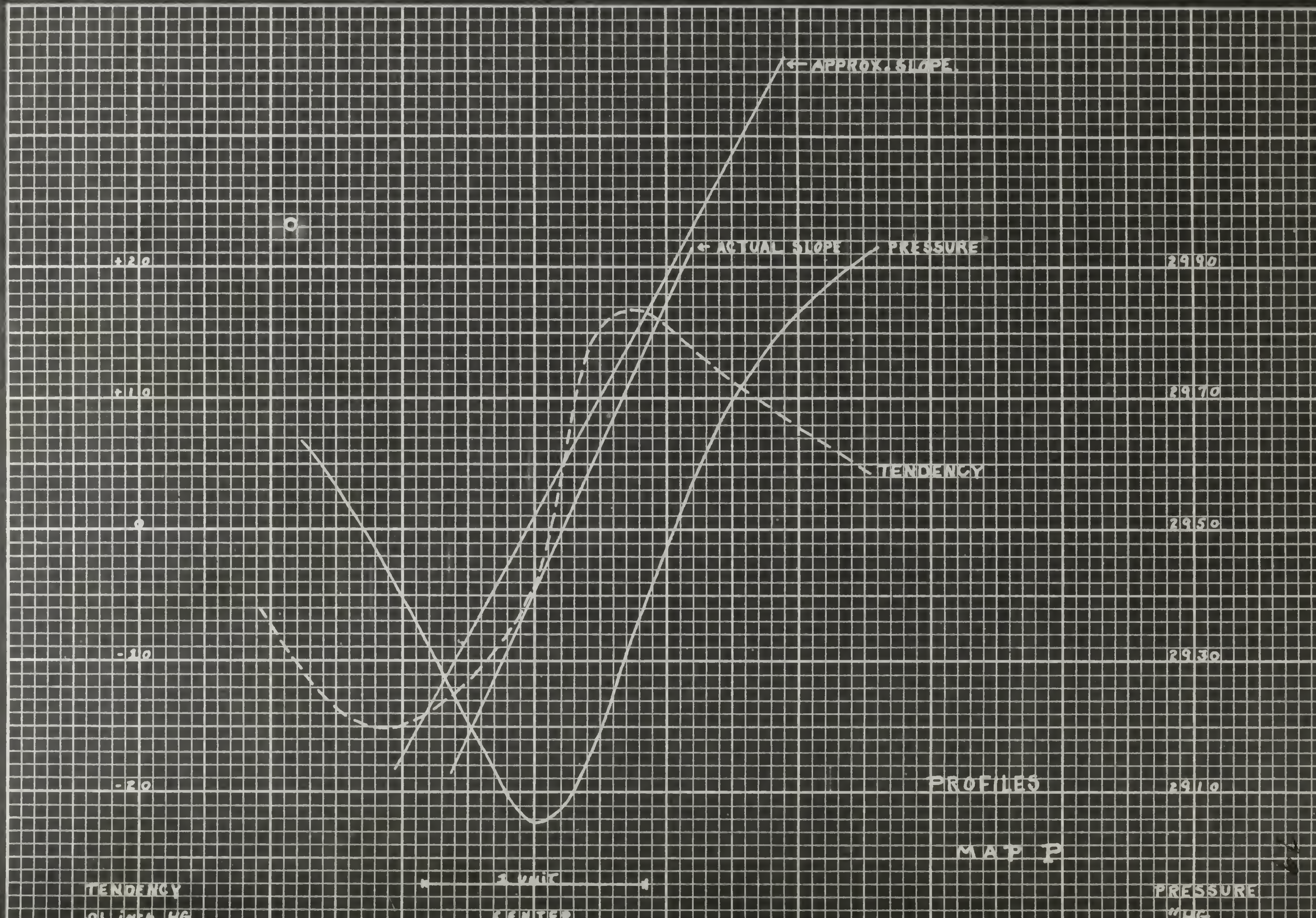
While the low had circular isobars, the line AB represented the isallobaric gradient and characteristic line, since a characteristic line can be drawn in any direction through concentric circles. Now we see that the isobars are becoming elongated and in this case, the line AB represents both the long axis (characteristic line) and the line of isallobaric gradient. Computation of the rotation of this line, will, of course, give us a measure of the rotation of the long axis of the system.

Drawing line EF and using DG as a unit we fill in the formula

$$C_L = -\frac{\frac{1}{2}[T_{1,0} - T_{-1,0}]}{P_{1,0} - 2P_{0,0} + P_{-1,0}} = -\frac{\frac{1}{2}[-10-(-6)]}{29.80 - 2(29.60) + 29.72} = \frac{1}{16} \text{ unit.}$$

12 hours gives 4/16 unit = 1/4 unit. Laying this off along DE we get the point H. Twelve hours later our long axis should lie along a line parallel to the line joining C and H. Computing the velocity of the center along AB we get, for unit length CS

$$C_L = -\frac{-14-(+18)}{29.74 - 2(29.05) + 29.60} = \frac{32}{124} = 0.258 \text{ unit.}$$



← APPROX. SLOPE.
← ACTUAL SLOPE
PRESSURE
TENDENCY
+20
+10
0
-10
-20
2990
2970
2950
2930
2910
PROFILES
MAP P
TENDENCY
.01 inch HG.
CENTER
PRESSURE
"HG

In twelve hours we get 4x.258 = 1.03 unit. We can not compute the velocity of C perpendicular to AB because of ocean area to eastward, but by inspection we can see that the isallobars run through the center perpendicular to AB, this means that there is no isallobaric gradient from West to East, therefore the point C will have no motion laterial to AB.

Knowing that the center will move according to rule II "The velocity of a pressure center falls between the isallobaric gradient and the longest axis, and the nearer the longest axis the more elliptical the center is." Here we have coincidence between the line of gradient and longest axis. Therefore we would expect the pressure system to become more and more elongated; and, since the long axis is rotating to the right, that the pressure center will follow a path curving in such a way as to follow the direction of rotation of the long axis. Laying off our distance of 1.03 unit along CS and drawing a perpendicular from this point to the line CH, we get the point R, which is the predicted position of the center as a resultant of the two motions.

This does not take acceleration into account, but it will be noticed that twelve hour periods are short enough time intervals that small accelerations do not have an appreciable effect.

The above computation shows again the value of constructing the pressure profile along the axis chosen. After drawing the two sides of the profile thru the values picked off the chart, we simply draw a smooth continuous curve to

connect the two points of lowest pressure. The lowest point of the profile then becomes our best estimate of the pressure at the center. This value of 29.05 was the one used in the computation. It can be readily seen that had we assumed the lowest reported pressure as that at the center we should have obtained an appreciably different result.

We will now turn our attention to the acceleration of the system, choosing as our whole unit the distance used as 1/2 unit for computing velocity. This is in order to approximate the slope of the tendency profile over the range of our differentiation.

Our acceleration formula now becomes

$$A_L \doteq - \frac{\frac{1}{2}[\Delta T_{1,0} - \Delta T_{-1,0}](P_{1,0} - 2P_{0,0} + P_{-1,0}) - (T_{1,0} - T_{-1,0})[T_{1,0} - 2T_{0,0} + T_{-1,0}]}{(P_{1,0} - 2P_{0,0} + P_{-1,0})^2}$$

we get:

$$A_L = - \frac{\frac{1}{2}(+3-0)[60] - [-14-(+18)](-14+8+18)}{[60]^2} = -\frac{(90+384)}{(60)^2} = -.13 \text{ unit per 3 hrs}$$

or, in terms of our velocity unit, $A_L = -.065$ unit per 3 hrs.

Computing our displacement for 24 hours we get:

$$S = Ct + \tfrac{1}{2}At^2$$

$$S = .258 \times 8 + \tfrac{1}{2} \times (-.065) \times 64$$

$$S = 2.06 - 2.08$$

$$S = -.02 \text{ unit in 24 hours}$$

This computation predicts that the center of the system will be in almost the same position 24 hours hence. An inspec-

tion of the later chart shows that it is decidedly in error. The computation of the instantaneous velocity gave us a reliable prediction for 12 hours, but the application of the erroneous acceleration term had led to an absurd result by 24 hours. Let us refer again to the previous discussion of accelerations.

To compute deepening or filling, we set

$$\frac{\delta P}{\delta \tau} = -8 - (+2) - (-15)$$

$$\frac{\delta P}{\delta t} = T_d = +5$$

In six hours we get $2 \times (+5) = +10$

From pressure profile lowest pressure	= 29.05
filling in 6 hours	= .10
Value of lowest pressure at 0200	= 29.15
Actually lowest reported	= 29.16

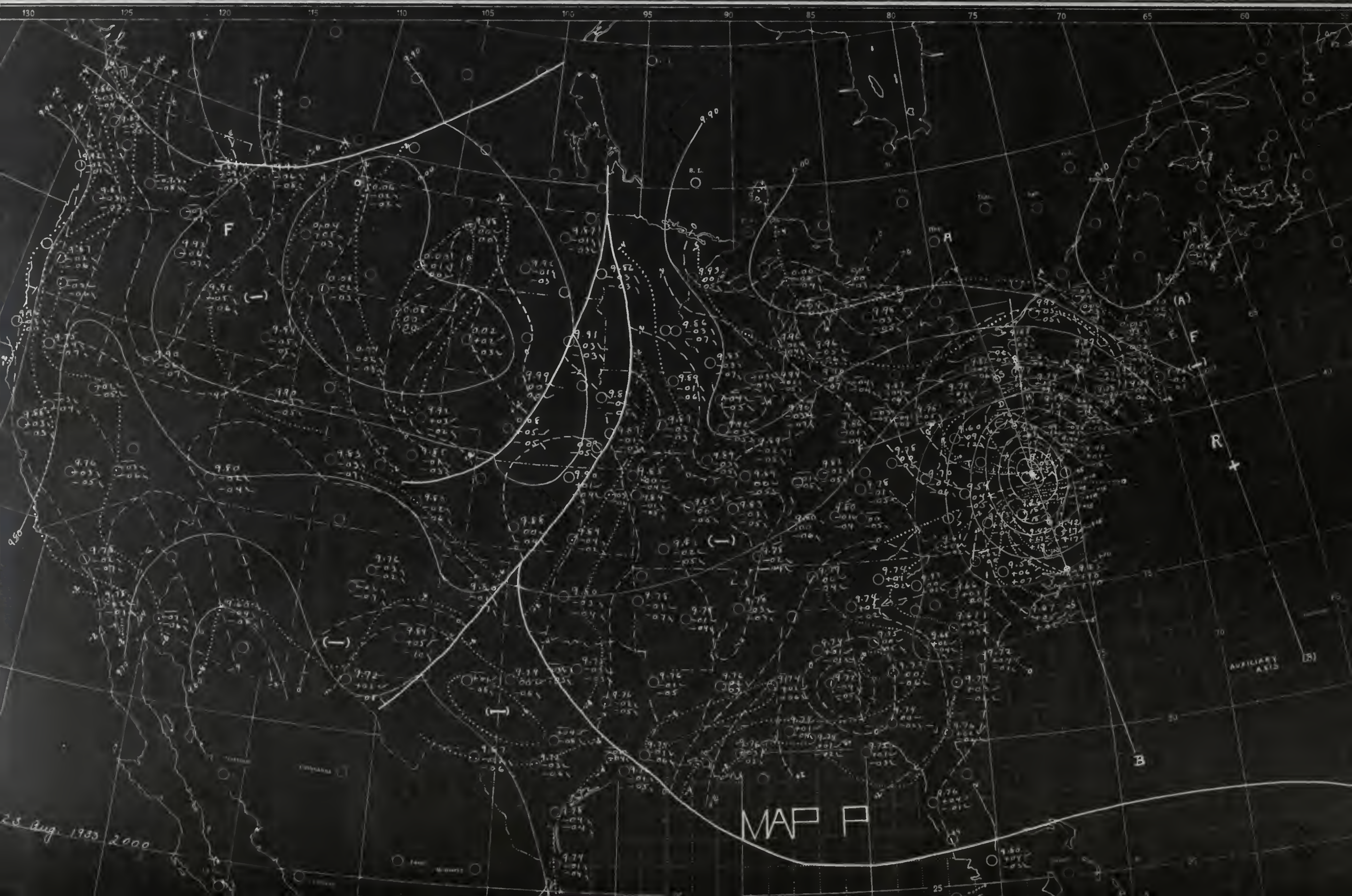
For twelve hours we get

$$\begin{array}{r} 29.05 \\ + \quad .20 \\ \hline 29.25 \end{array}$$

actually there was reported at 0800 24 August 29.30

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.



MAP Q.

The long axis AB has rotated to the right, but we notice a more symmetrical distribution of isallabars about this axis. This would lead us to believe that the rotation would not continue. Calculating velocity of point D towards E, using DG as a unit

$$C_L = -\frac{\frac{1}{2}[-8-(-5.5)]}{29.77-2(29.50)+29.77} = \frac{1.25}{59} = .02 \text{ unit per 3 hrs.}$$

This shows a continued rotation of the long axis to the right but at an almost negligible rate.

Calculating velocity along AB, getting $P_{0,0} = 29.16$ from the pressure profile curve, using CS as a unit, we get

$$C_L = -\frac{[-10-(+15)]}{29.68-2(29.16)+29.48} = +\frac{25}{84} = .295 \text{ unit}$$

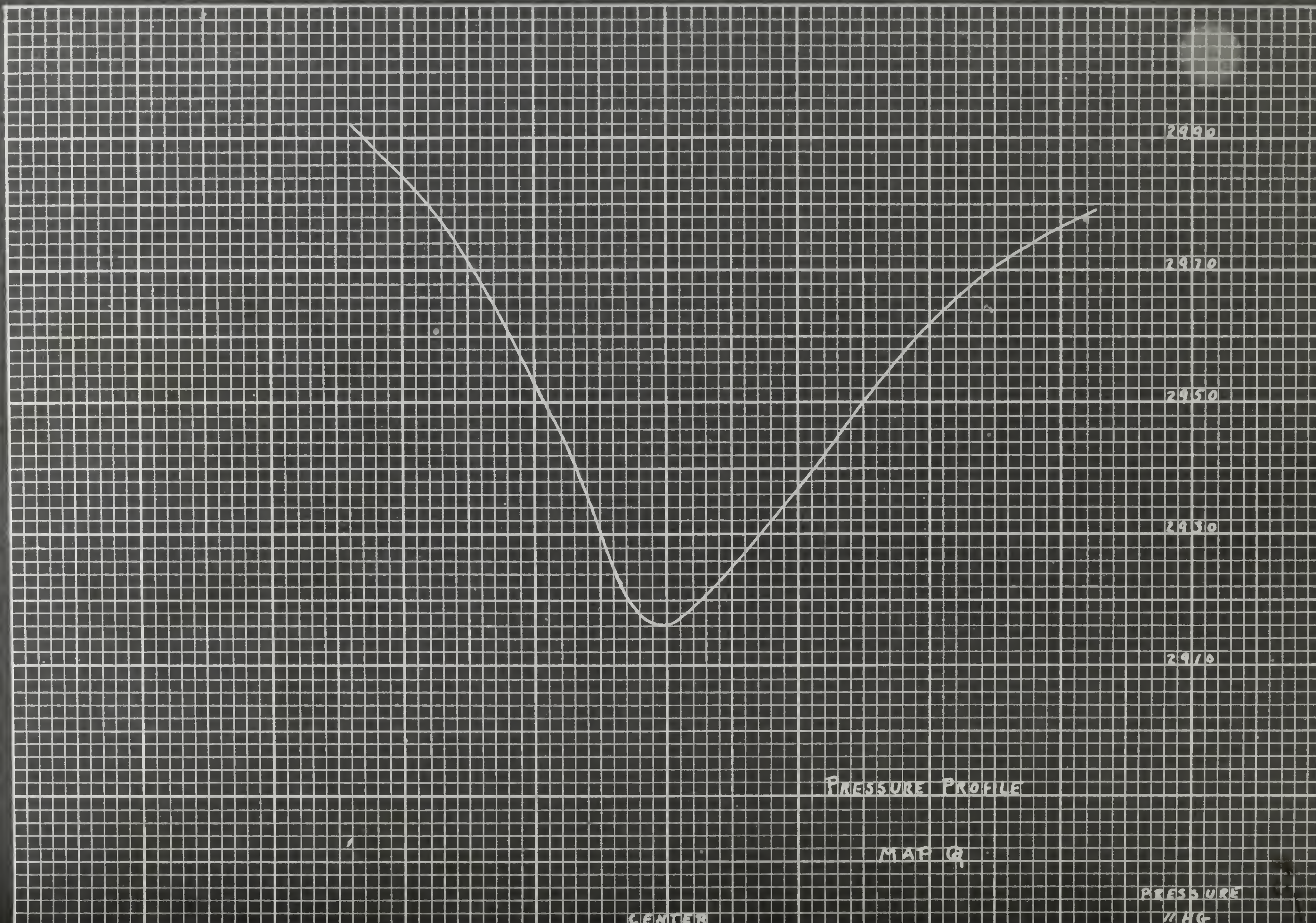
12 hour displacement = 4 x .295 = 1.18 unit.

Calculating the velocity along JK we get, using CL as a unit

$$C_L = -\frac{\frac{1}{2}[-2-(-3)]}{29.72-2(29.16)+29.70} = \frac{.5}{110} \text{ unit.}$$

This value is insignificant, being beyond the limits of accuracy of the methods.

Then we can say that the motion will be all along the line AB accompanied by a slight rotation of the long axis to the right, which would be expected to swing the center slowly towards the right. This results in a slightly greated displacement than was observed, but with an accuracy close enough for practical purposes. The Point R is the calculated position of the center.


2990
2970
2950
2930
2910
PRESSURE PROFILE
MAP Q
PRESSURE
" HG
CENTER

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP R.

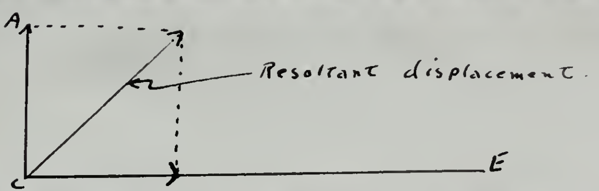
Using unit length CS for computations along AB, note from profile of the tendencies how the unit chosen approximates the slope of the profile as it passes the center. Had we chosen a larger unit the approximate slope would have been entirely erroneous because at point S the slope of the tendency profile changes.

$$C_L = -\frac{\frac{1}{2}[-10-(+11)]}{37} = \frac{10.5}{37} = .284 \text{ unit per 3 hours}$$

repeating the process along axis EF, using CG as a unit we get

$$C_L = -\frac{\frac{1}{2}[-5.5-(+1)]}{70} = \frac{3.2}{70} = .045$$

Resolving the two velocities along their computed axes and applying the displacement for 12 hours thus:



we get the computed magnitude and direction of motion, i.e. the resultant displacement.

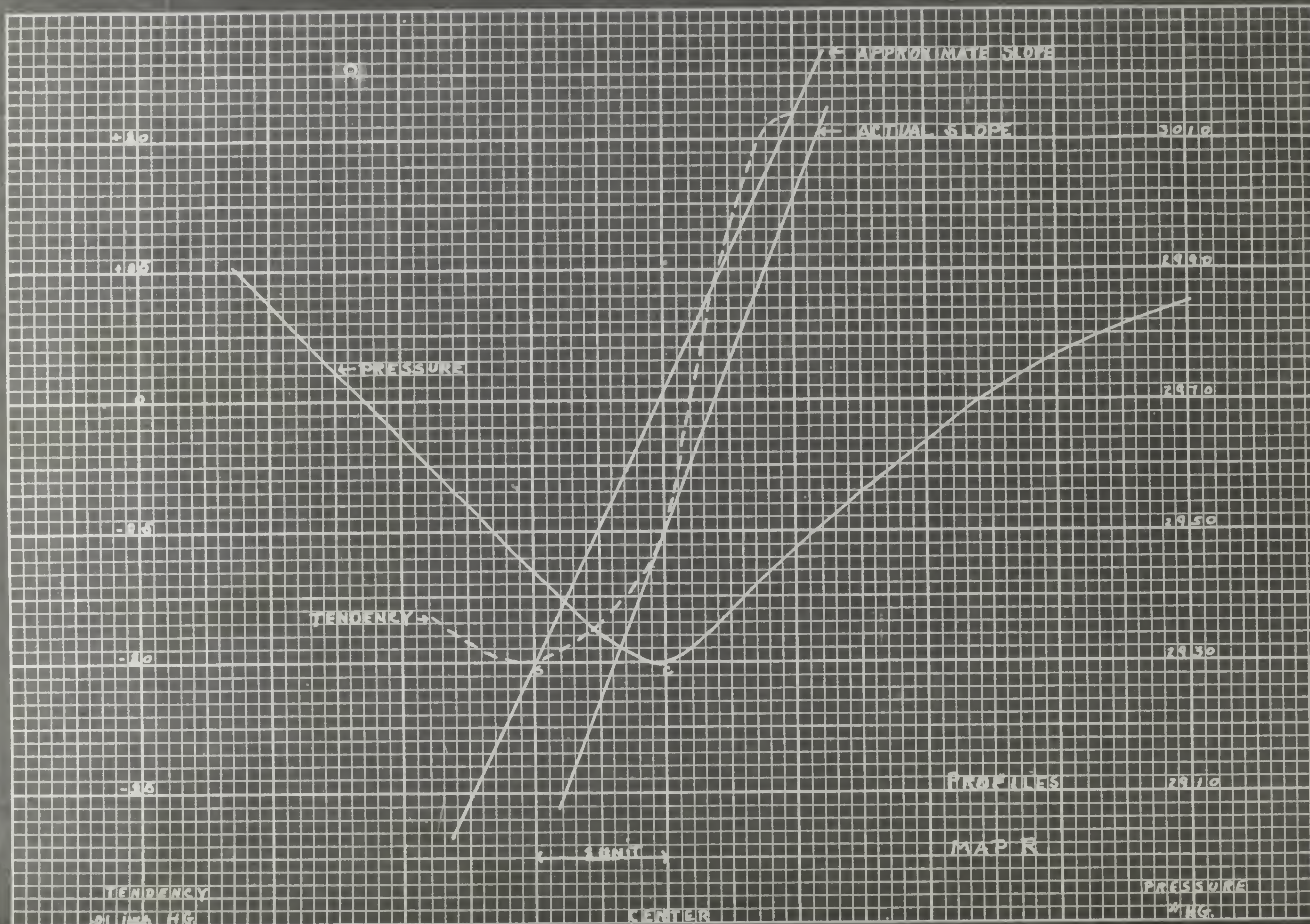
Hence

along CA, $4 \times .284 = 1.136$ unit in 12 hours (unit = CS)

along CE, $4 \times .045 = .18$ unit in 12 hours (unit = CG)

Plotting on the chart we get point H as the computed point.

We show here the acceleration as computed by two different persons to show the effect of individual judgment and of



APPROXIMATE SLOPE
ACTUAL SLOPE
PRESSURE
TENDENCY
+.10
+.05
0
-.05
-.10
-.15
3010
2990
2970
2950
2930
2910
S
C
1 UNIT
PROFILES
MAP R
TENDENCY
.01 inch HG.
CENTER
PRESSURE
" HG.

using only slightly different values in the various members.

We use the formula:

$$A_L = -\frac{(\Delta T_{\frac{1}{2},0} - \Delta T_{-\frac{1}{2},0})(P_{1,0} - 2P_{0,0} + P_{-1,0}) - 2\,(T_{\frac{1}{2},0} - T_{-\frac{1}{2},0})\,(T_{1,0} - 2T_{0,0} + T_{-1,0})}{(P_{1,0} - 2P_{0,0} + P_{-1,0})^2}$$

$$A_L = -\frac{[2.5 - (+9)]\,37 - 2[\{(-8.5) - (+6)\}\{-10 - 2(-5) + 11\}]}{(37)^2}$$

$$A_L = \frac{19.5}{1370} = +.014 \text{ unit per tendency period}$$

This shows a slight positive acceleration.

$$A_L = -\frac{[3 - (+9)]\,37 - 2[\{(-9) - (+7)\}\{-10 - 2(-5) + 11\}]}{(37)^2}$$

$$A_L = -\frac{130}{(37)^2} = -.095$$ unit per tendency period

which shows a decided retardation.

It will be noticed that actually the differences in the values selected are very small and yet the results do not even agree in sign. The magnitudesof the results are likewise small, but when we consider that the acceleration enters into our displacement calculation with the square of the time interval, we realize the effect it has on a longer period.

Deepening or Filling

$$T_d = T_0 - T_M$$

$$T_d = -5 - (+2) + 06 = -01$$

We get a computed deepening of -01 every three hours. This would give $(2 \times -.01 = -.02) + 29.30 = 29.28$ pressure minimum at 1400 on 24 August. Actually the lowest pressure on the pressure profile at that time is 29.34.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE. WEATHER MAP. WEATHER BUREAU.

MAP S.

By the time we reach this map our pressure system is reaching an area where we have fewer observations. Consequently we shall soon be unable to make many computations. Already the uncertainty of the isallobaric distribution in the North makes it necessary to choose rather a short unit length in that direction.

We drew our axes, AB and EF, along the long and short axes of our system. We chose a unit of length CS to the north and CG to the East. We will now compute the velocity of the center along these two directions.

Taking the EF axis first with our unit CG:

$$C_L = -\frac{[-3-(+2)]}{29.60-2(29.35)+29.61}$$

$$C_L = \frac{5}{51} \cong \frac{1}{10} \text{ unit per 3 hours}$$

or .4 unit in 12 hrs., and in the E direction.

Now taking the AB axis with CS unit length:

$$C_L = -\frac{\frac{1}{2}[-6-(+5)]}{29.52-2(29.35)+29.55}$$

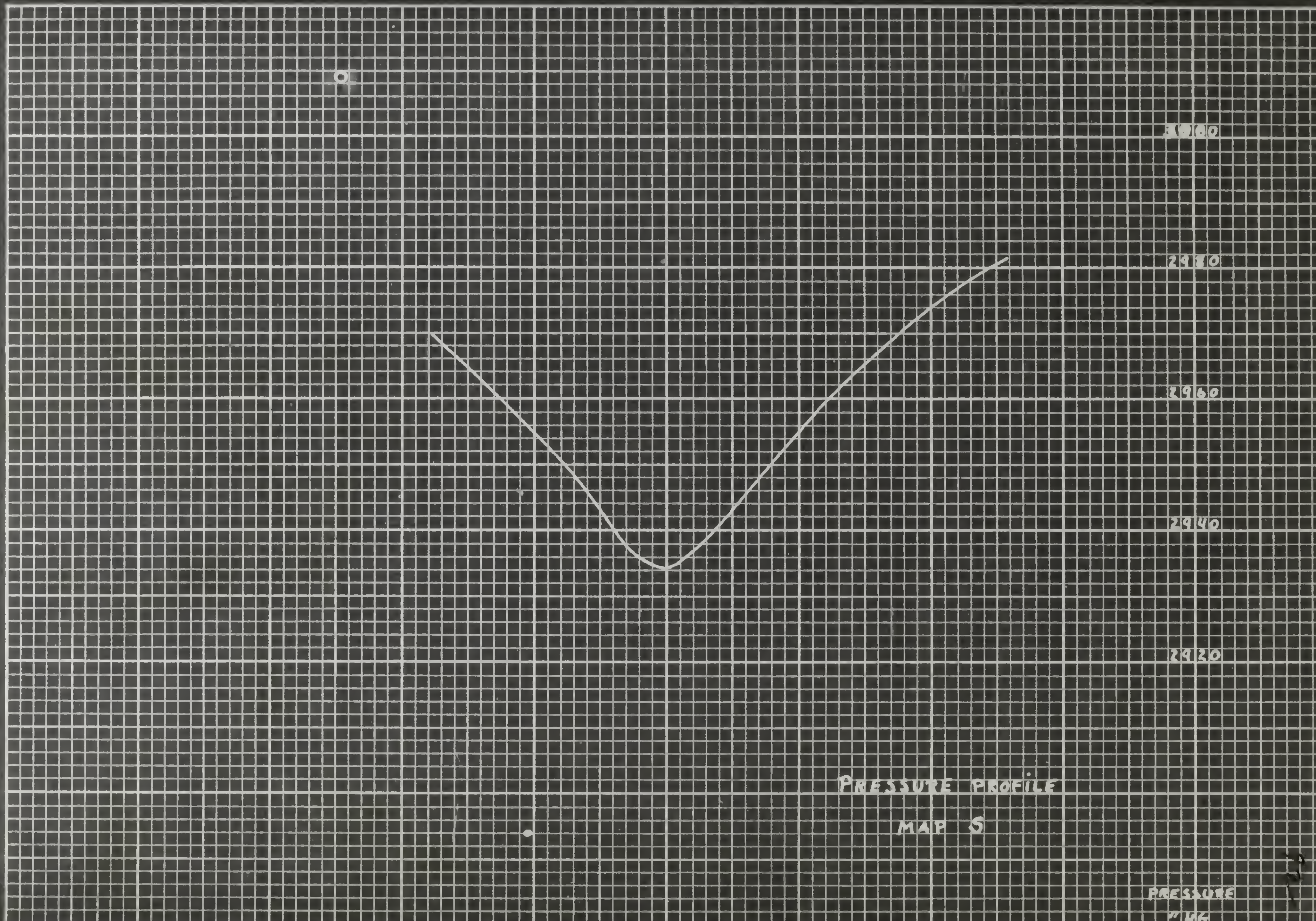
$$C_L = -\frac{-6.5}{37}$$

$$C_L = .175 \text{ unit per 3 hrs.}$$

or .7 unit in 12 hours in the A direction.

Laying off these lengths in the proper directions and taking the resultant we get the point H as our predicted position of the center at 0200 25 August. This agrees closely with the observed location of the center.

Now let us compute the deepening in the usual manner


3000
2980
2960
2940
2920
PRESSURE PROFILE
MAP 5
PRESSURE
" HG

$$T_d = T_o - T_M$$

$$T_d = [0-(-2)] - (-2)$$

$$T_d = +4$$

Hence we conclude the center is filling at the rate of .04 every 3 hours or .16 in 12 hours. This gives a predicted value of 29.51 for the center at 0200. The lowest reported was 29.47.

U. S. DEPARTMENT OF AGRICULTURE. WEATHER MAP. WEATHER BUREAU.

Map A.A.

MAP T.

Drawing AB along the isallobaric gradient we will use the approximate method for computing velocity, since there is a lack of reports in the forward portion of the low pressure system. By inspection we can see that the isallobars run in general perpendicular to the line AB through the center. This means that $T_{1,0} - T_{-1,0}$ will come out to be zero and therefore along a line perpendicular to AB the velocity will be zero. Computing the velocity along AB we take the approximate formula

$$C_L = - \frac{-T_{-\frac{1}{2},0}}{P_{-1,0} - P_{0,0}} = + \frac{6}{9.60 - 9.35} = \frac{6}{25} \text{ unit per 3 hrs}$$

In twelve hours we get $4 \times \frac{6}{25} = \frac{24}{25}$ or about one unit of length CS′.

This puts the center at 0800 on 25 August at point S which compares favorably with the map for that date.

Computing the deepening by use of this approximate velocity we get

$$T_d = +01 - (+01) - (-04) = +04$$

$$.04 \times 4 = .16 \text{ inch rise in 12 hours}$$

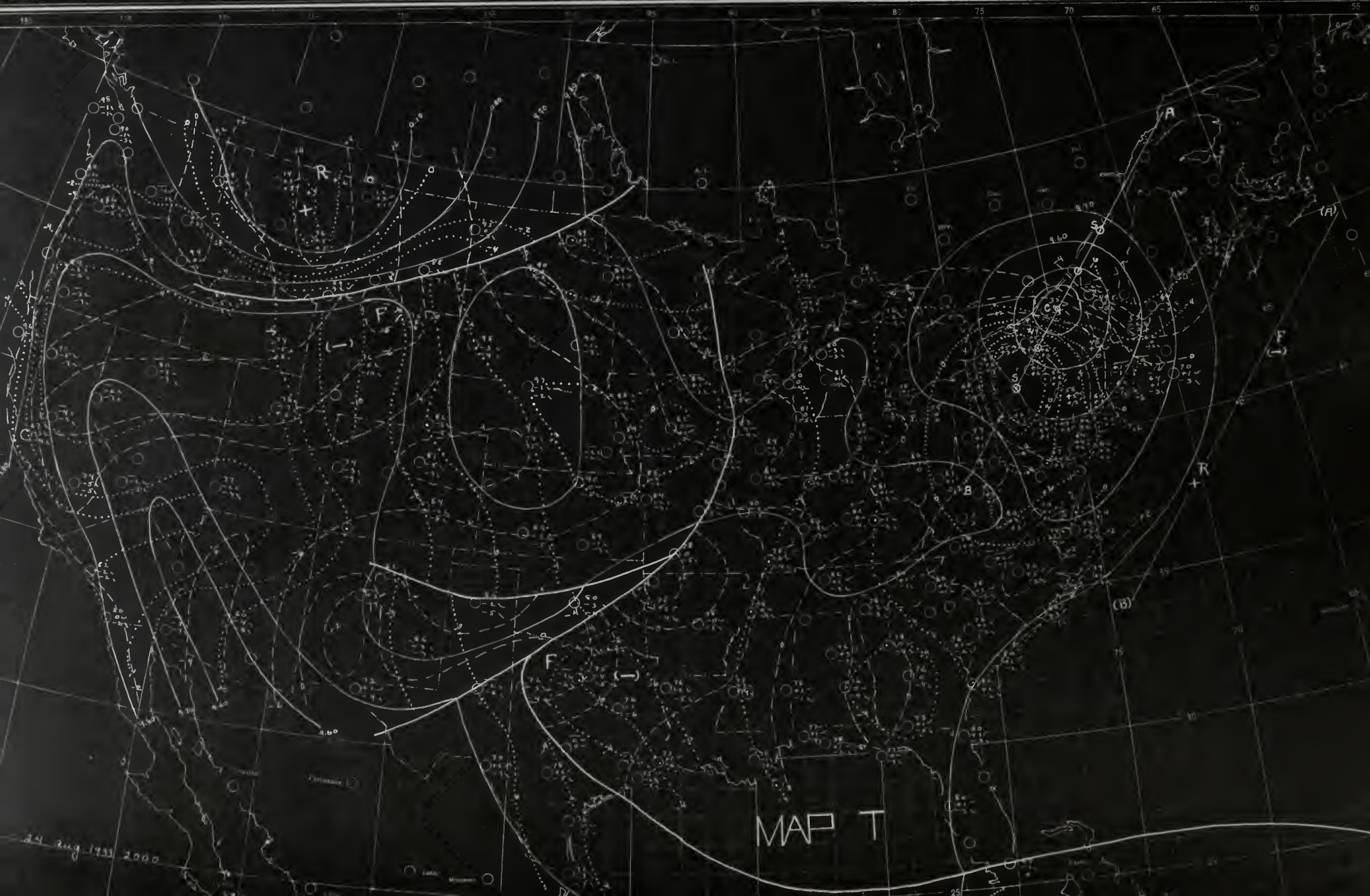
$$29.35 + .16 = 29.51$$ pressure computed.

Lowest pressure reported at 0800 25 August is 29,48 inches of mercury.

There are included in this series the maps for the succeeding 24 hours. These may be required by the reader for the purpose of checking the location of the system from the previous computations.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

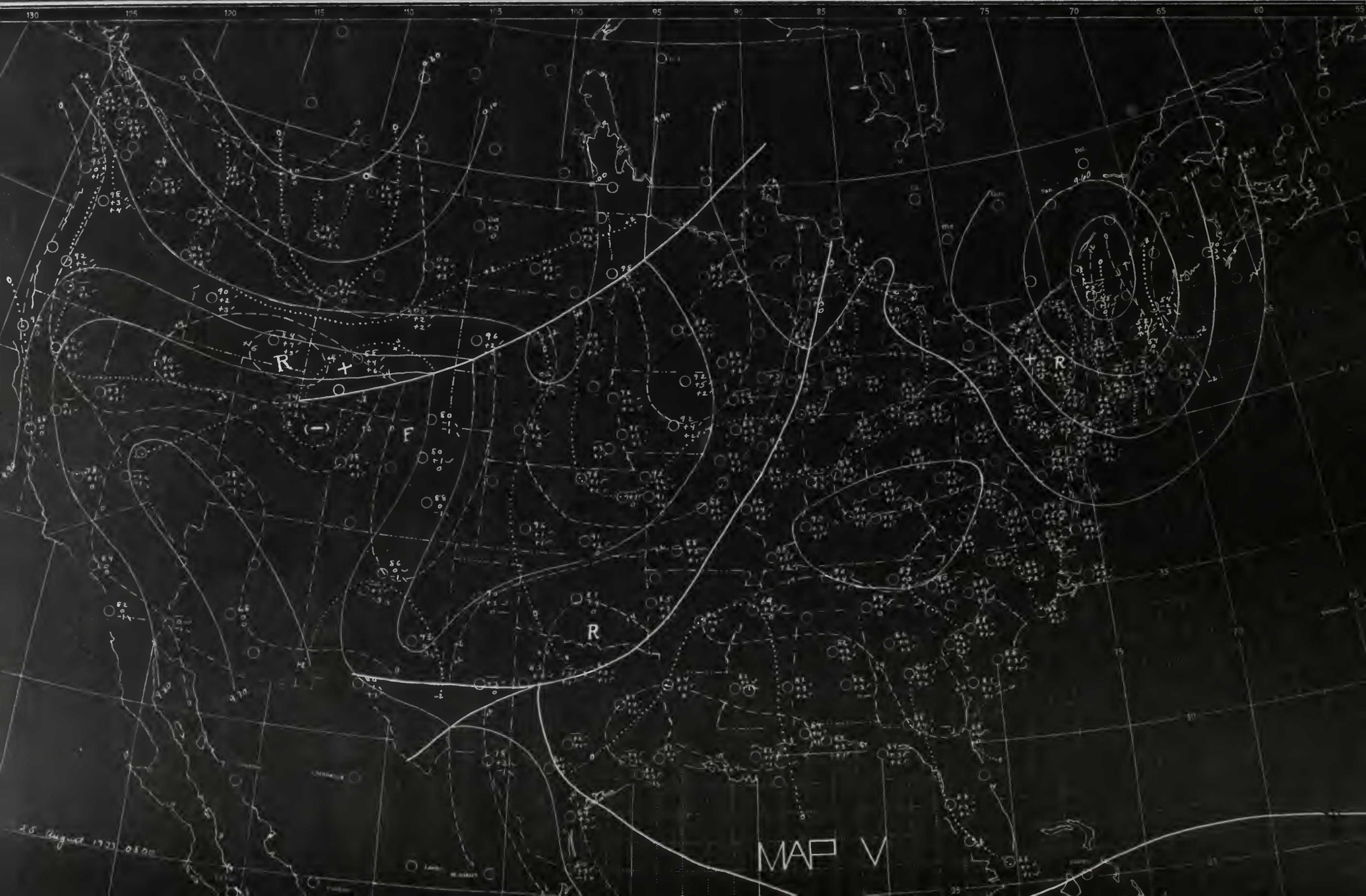
Map AA.



U. S. DEPARTMENT OF AGRICULTURE. WEATHER MAP. WEATHER BUREAU.

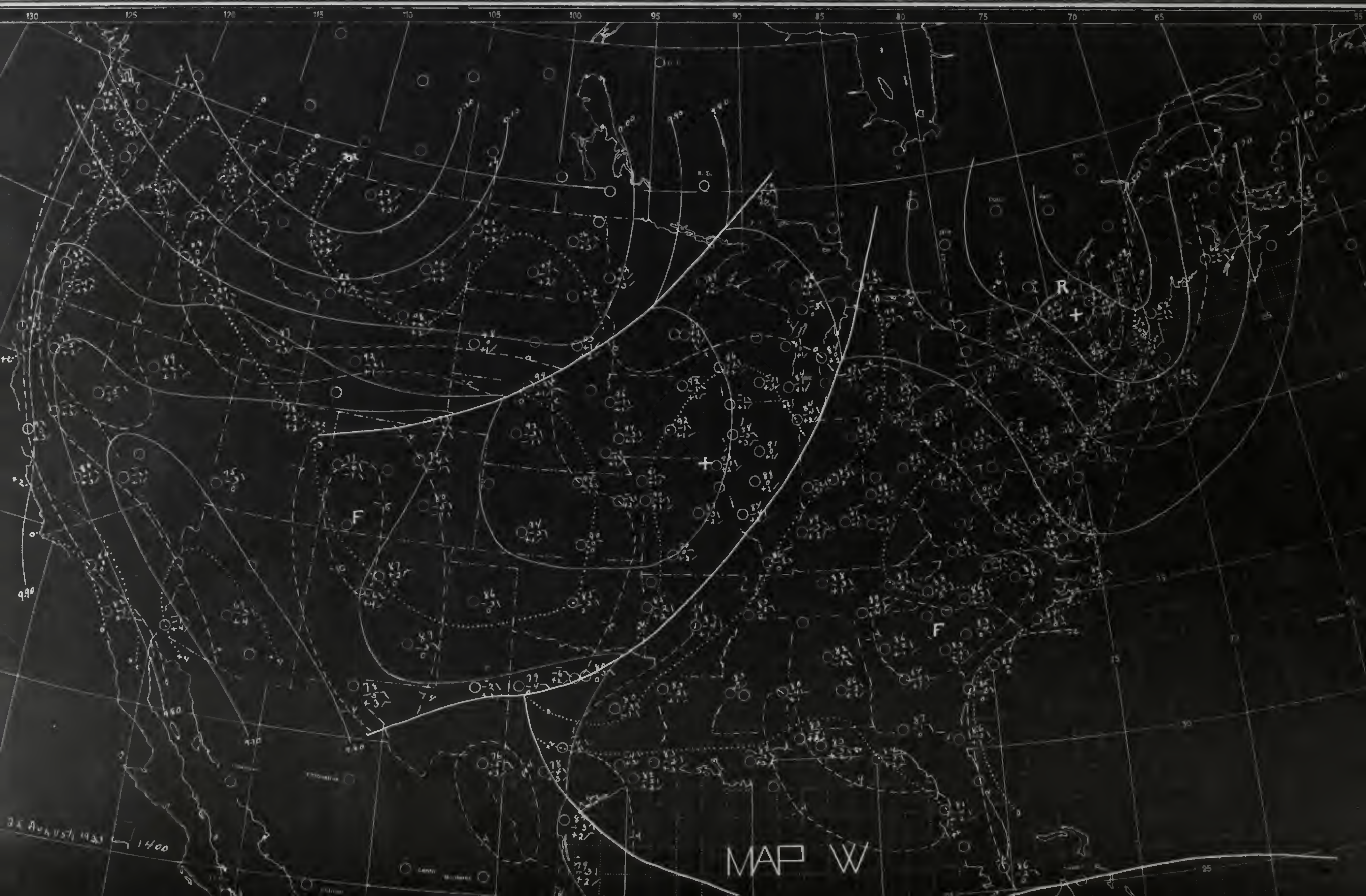
Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.



Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.



Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

The following two charts depict the twelve hour positions of the center of the hurricane, and these positions are connected with a dotted line which represents the actual path traversed by the disturbance. The thin soled lines represent the computed displacements of the center. Corresponding numbers are assigned the computed and actual positions for the same instant, for instance, number 2 computed position is that calculated position of the center which actually arrived at number 2 on the dotted line.

It may be remarked that the exact position of the center is subject to the drawing of isobars and that the results indicated are considered within the limits of accuracy expected. It will be seen that in each instance the predicted location of the center lay within the isobar of lowest pressure.

M.
Co.
Dou.
San.
W. E.
Hbs.
0200 - 25 AUG.
1400 - 24 AUG
0200 - 24 AUG
1400 - 23 AUG
Approximate method
0200 - 23 AUG
35
65
70
75
30
PATH of Hurricane
Computed path

Co.
Dou.
San.
W. E.
Hby.
Approximate method
5
5 0800 - 25 AUG
4
4 2000 - 24 AUG
3
3 0800 - 24 AUG
2
2 2000 - 23 AUG.
1 0800 - 23 AUG
65
35
70
75
30
PATH of Hurricane
computed path

IX. Weather Situation over the United States
13-19 September 1933.

There follows a detailed analysis, with reproductions of the original maps.

Following the last map is a plot, showing the path of the Hurricane and the areas of greatest negative tendency for each period.

MAP 1

This series opens with a map which apparently represents an inactive pressure situation over the United States. At first glance, the question which naturally arises in considering Map 1 is that of the future behavior of the low pressure area centered over Missouri. We observe the reported tendencies at the top of the warm sector are plus 04. As the normal pressure change of this area during this time is between plus 02 and plus 03, we should take this as indication that the trough is slowly filling. This is borne out by both the rules for deepening and filling of trough lines, and warm sector cyclones. See rules 25 and 32.

This indicates that the aforementioned LOW will fill and disappear and that it will not become a predominating factor in the future pressure distribution. This process of filling can be verified on later maps.

Turning our attention to the High Centered North of the Great Lakes region, we notice that the wedge line curves roughly around the front in such a way that we have a wedge in advance and in the rear of the warm sector. Inspection of the effective tendencies along the wedge lines show that the system is filling.

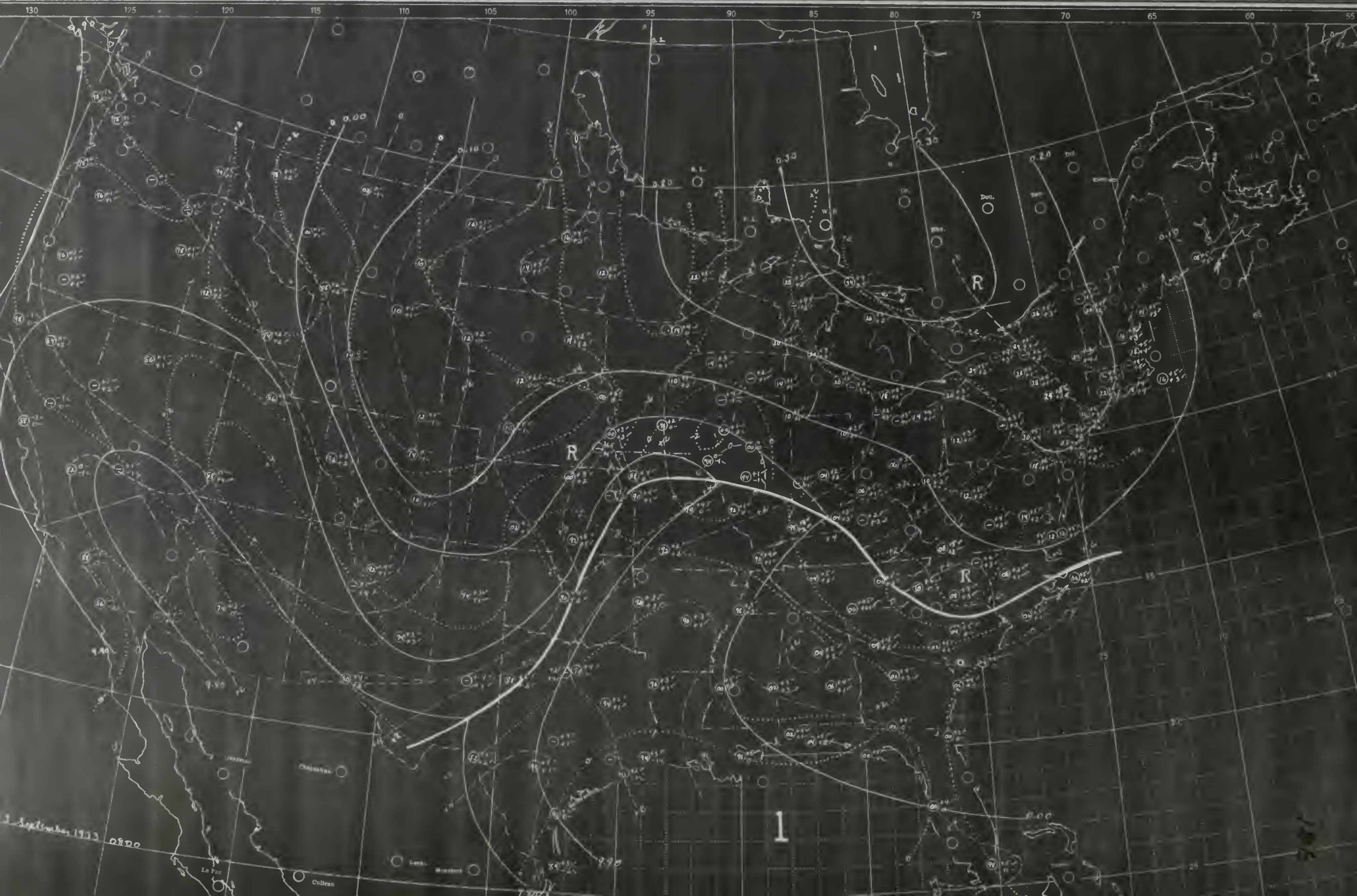
This filling presents resistance to the passage of the Front into the High Pressure area.

Inspecting the isallobaric distribution at the front, at the top of the warm sector, we would expect a small movement

along the warm sector isobars in a North Easterly direction, since we note that there are larger tendencies to the South at the Front than there are at the North. This is an example of the practical application of the principles of these methods without resorting to computation. Without going into computations at this point, we must expect the general pressure distribution to behave thus: The High over the Great Lakes will slowly fill, the Front will progress slowly in a North Eastward direction and the Low centered over Missouri will gradually disappear. This means that the trough will be become less intense.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.



MAP 2

This map shows little change in the general situation. Developments are taking place as expected from the previous map.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP 3

On this map the effective tendencies at the Front over Indiana and Ohio are approximately equal on both sides, hence we would expect very little movement of the Front in this region. Northwest of the Front, over Missouri, we notice larger tendencies than we see Southeast of the Front in the same region, hence we would expect motion in a South Easterly direction of this portion of the Front.

Both the dashed and dotted isallobars show extensive areas of effectively falling tendencies over Montana and Idaho, indicating the rapid approach of the Front from the Pacific Ocean.

Turning our attention to the South Eastern section of United States, the coastal stations of Georgia and Florida report zero tendencies. Inasmuch as the normal tendency at this period is about plus 03, this indicates effective minus 03 tendencies. The approximate position of the Hurricane is as indicated on the map. These falling tendencies are apparently caused by the proximity of this Low center, whose direction of motion is as yet undetermined. At present the isallobaric distribution on the continent gives no indication as to the probable course of the disturbance.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE. WEATHER MAP. WEATHER BUREAU.

MAP 4

The general pressure distribution remains unchanged. A building up of effective tendencies over New England of plus 01 has persisted for two tendency periods. Minus 04 tendencies along the coast of Maryland and Pennsylvania indicate a condition for retreat of the Front lying along this region, to the Northward. Notice that this is the same development that appeared in the first series as well as the effectively falling tendencies along the Southern Atlantic coast.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP 5

The High Pressure area continues to build up slowly over Northern New England at the rate of approximately plus 01 every three hours.

The falling tendencies along the Southern Atlantic Coast continue to fall effectively at the approximate rate of minus 03. Note the character of the general falling tendencies along the South Atlantic Coast. There is no area of concentrated falls which might indicate a point towards which the hurricane might be expected to progress, rather there is a general fall prevailing which indicates its approach but not its path.

The area of rising tendencies centered over Northern Indiana and Illinois indicate a continued motion of this portion of the Front to the South Eastward.

The marked falling tendencies in advance of the Front in the Rocky Mountain region and the slight rises behind it, indicate a rapid motion of this front to the Eastward. The movements of these two fronts indicate a transport of air masses across the United States from West to East. This, coupled with the rising pressure over New England would seem to indicate at present, a general opposition to the approaching hurricane.

This general conclusion is further strengthened by reference to the previous series. In that series we observed a generally stagnant condition over the United States with a quasi-stationary front over the central states and comparatively little transport of air masses.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP 6

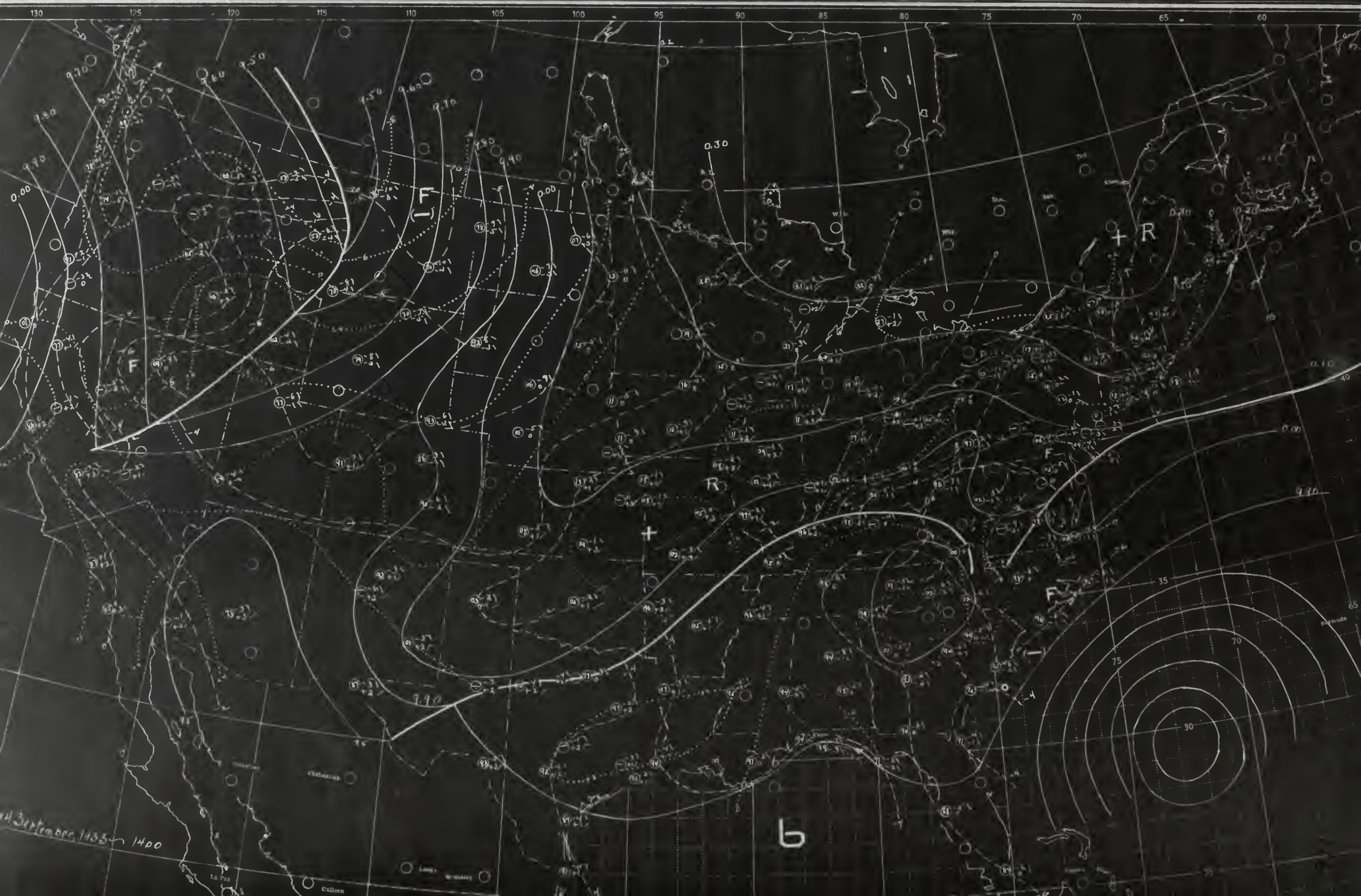
The general tendencies along the South Atlantic Coast continue to fall, effectively minus 03. The absence of concentrated falls continues to be noticed.

The movements of the two fronts occurred as anticipated and the same condition prevails for the continuation of the movement of the Western Front.

This map shows that the trough, originally centered over Missouri has filled and now the pressure situation over the Eastern United States is becoming very flat.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP. WEATHER BUREAU.



MAP 7

Here again there is little change in the rate of development. That is, the falling tendencies along the South Atlantic Coast continue at the same rate and in the same general region. The rapidly moving front over the Rocky Mountains continues Eastward. The Northern High continues to build up slowly as can be seen from the plus 02 dashed isallobar which indicates an effective plus 01.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP 8

The dotted minus 02 isallobar along the South Atlantic Coast indicates a contin ation of the same general falling tendencies. The tendencies for the past three hours, however, show a slight increase in the rate of fall at Hatteras, from an effective minus 03 to an effective minus 05 at this one station. The area in the vicinity of Hatteras also shows a small increase in the rate of fall amounting to about minus 01. As before, the isallobars arrange themselves parallel to this section of the coast without any marked concentration.

The rate of change of the pressure distribution over the United States remains practically steady, that is, the Western Front moves Eastward at a steady and rapid rate and the Northern High continues to build up slowly.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP 9

Here we see the isobaric system of the hurricane definitely moving on to the coast. The direction of motion of the hurricane has been in a general North Westerly direction, i.e., perpendicular to the minus 03 isallobar which has been running along the South Atlantic Coast, this of course shows the motion to have been along the isallobaric gradient which is as expected. On this map the dashed tendencies at Hatteras and Wilmington are effectively minus 08, while at Charleston and Savannah, the effective tendencies are minus 04. This indicates that the isallobaric gradient is in a line from the center of the hurricane toward a point somewhere between Hatteras and Wilmington. Therefore, we should expect its motion, at present, to be in this direction.

Having decided upon the direction of motion of the disturbance, we will consider the general pressure system on the continent. Effective dashed tendencies over Maine are plus 04, over Southern New England plus 02, and the area to the north of the Atlantic Front are plus 01. The Rocky Mountain Front shows continued Eastward advance. The area North of the Middle states Front shows indications of a slow fall in tendency values. The pressure gradient, however, continues to be very flat, so we can compute no motion. At the present moment no further deductions regarding future developments can be made.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

Map AA.

MAP 10

Considering the isallobaric distributions for the two periods available on this map, it is evident that the dotted isallobars show maximum fall in the vicinity of Wilmington, while the dashed isallobars show the maximum fall to be in the vicinity of Hatteras. This indicates a change in the direction of the isallobaric gradient, hence a change in the direction of motion of the center of the disturbance. Now, at 1400, 15 September, the isallobaric gradient lies in a line extending between Hatteras and Cape Henry, thus indicating a change in direction of motion of the center from North West to North.

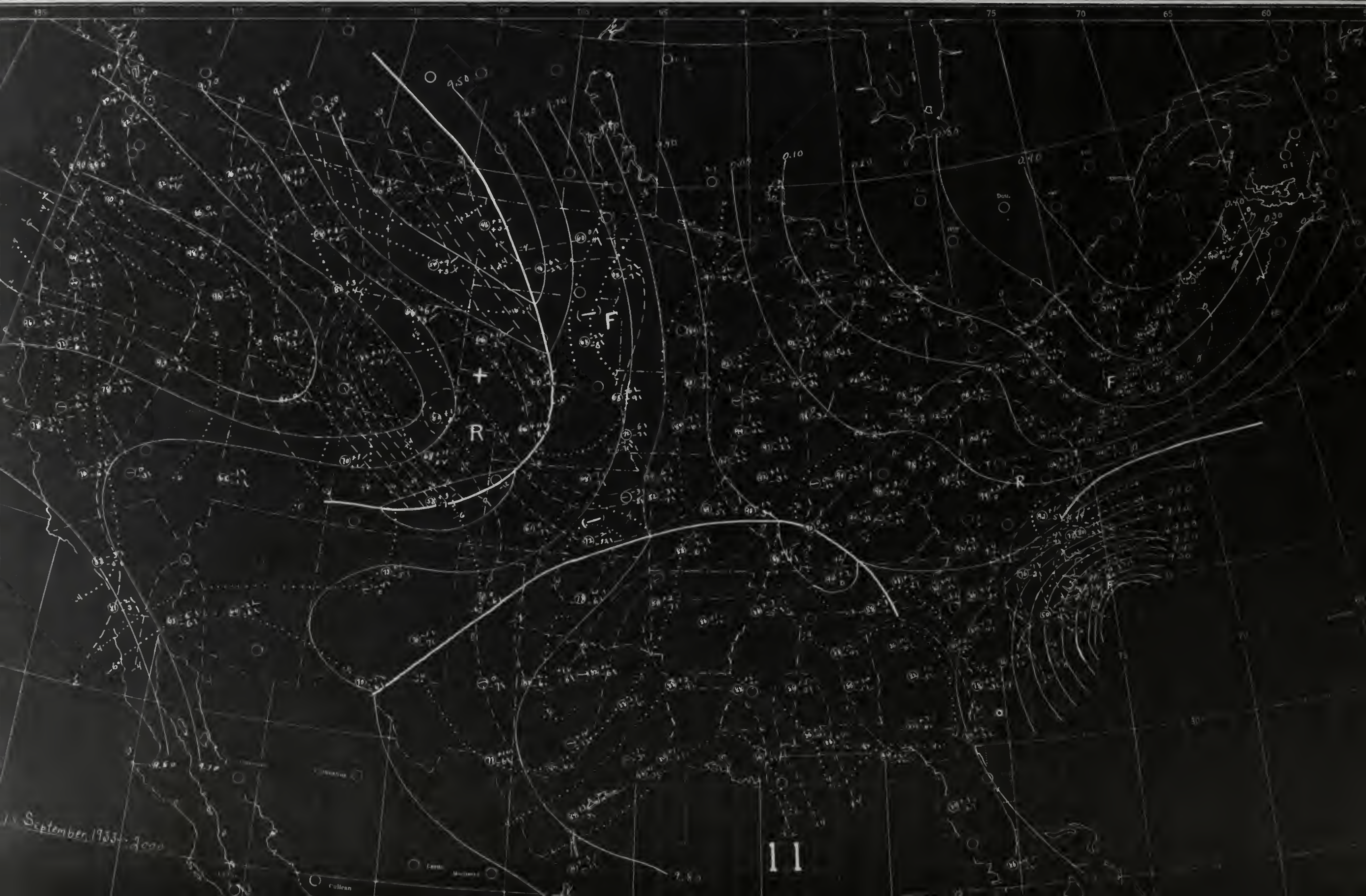

10

MAP 11

The point of maximum fall for both the dotted and dashed isallobars is at Hatteras. There are no corresponding tendency falls at any of the other observing stations. This shows that the isallobaric gradients are not progressing inland and bears out our determination on the previous map of a northerly direction of motion of the Hurricane. We also find a corner in the tendency characteristic at Wilmington which indicates that lower and lower isobars have ceased crossing this station and its pressure is now rising. Stations to the South of Wilmington, on the coast are behaving similarly, therefore the center of low pressure is moving away from Wilmington and since it is South of Hatteras, we can definitely say that the Hurricane will not pass inland South of Hatteras and its motion at present is directed Northerly. In addition the area of effectively rising tendencies of between plus 01 and plus 02 over Western North Carolina and Western Virginia including Baltimore would indicate that the Hurricane will not pass inland over this area. On the other hand, there is an area of effective minus 01 tendencies north of the Atlantic Front along the entire coast which indicates a general area of falling pressures in that direction. This strengthens the determination of a continued northerly direction of motion of the Hurricane.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.



MAP 12

Looking over the isallobaric distribution on this map we see that Hatteras reports the maximum fall for both periods. The area of large falls continues to be to the North of Hatteras along the North Atlantic coast. On the last map this area showed an effective tendency of minus 01. For the period 2000 to 2300 (dotted isallobars) it shows about an effective minus 03, and for the period 2300 to 0200 (dashed isallobars) an effective minus 05. This increase in the rate of fall extends up the coast as far North as Nantucket. To the west the falls are less for both periods. Comparing this isallobaric gradient with those of the past maps it follows that we should expect that the hurricane will not travel farther westward, and that any future change in its direction of motion will be to the Eastward of its present northerly course. The Western Front continues to move rapidly Eastward and with the general falling tendencies over New England, we conclude that the High over this region is moving off the map, in advance of the two approaching low pressure systems.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP 13

The center of the disturbance passed Hatteras as shown by the barograph characteristic and the isallobaric gradient shows definitely its general direction of motion. The minus (dotted) isallobaric center of fall is at Hatteras, the dashed isallobaric center of fall has now moved off the coast. Notice that the magnitude of the falls at Norfolk and Cape Henry are decidedly less than those previously shown at Hatteras. This indicates without question that the isallobaric gradient is continuing to move to the right, away from the coast and the disturbance, in following this gradient will move away, rather than towards the continent.

Heretofore in this series no computations of velocities have been made because of the general condition. Specifically, lack of observing stations along the Atlantic Front, very slight pressure gradient about the Middle States Front and of course in the Rocky Mountain region, the fictitious pressures would be expected to give unsatisfactory results.

Now the Western Front has moved so far eastward that the pressures in the trough represent the real surface gradient, but the scarcity of observing stations in the area of the Northern Great Lakes Region makes the true gradient still questionable. Notice that there are three isobars faired in between Duluth and Escanaba. Therefore, any computations made along the Northern section of this front would not be expected to be any more valid than the assumed isobaric gradient. Such conditions show the limitations of the use of this numerical method. How-

ever, qualitative analysis by consideration of the principles of these methods is always possible and will yield consistent results.

Choosing Point C on the Front as the Northernmost point at which the pressure gradient as drawn is reliable, we compute the velocity of this point along the line AB. AB is drawn roughly parallel to the 29.70 isobar to the west of the Front.

Filling in the Frontal formula

$$C_f = -\frac{\frac{\partial P_1}{\partial t} - \frac{\partial P_2}{\partial t}}{\frac{\partial P_1}{\partial x} - \frac{\partial P_2}{\partial x}} = -\frac{-2-(+4)}{\frac{10}{h} - 0}$$

$$= .6\,h \text{ every } 3 \text{ hours.}$$

Extrapolating this velocity along AB for 12 hours we get

$$4 \times .6\,h = 2.4\,h \quad \text{or} \quad \text{Point } S$$

This agrees nicely with the position of the front 12 hours hence. Note that the unit h is equal to the distance CD, the distance between unit isobars along the axis. This computation shows that the rapid motion of the Western Front will continue. The warm sector shows an occluding velocity along the warm sector 29.80 isobar of the following magnitude, using the occluding velocity formula.

$$C_c - C_w = \frac{\frac{\partial P_1}{\partial t} - \frac{\partial P_2}{\partial t} - \frac{\partial P_3}{\partial t} + \frac{\partial P_4}{\partial t}}{\frac{\partial P_1}{\partial x}}$$

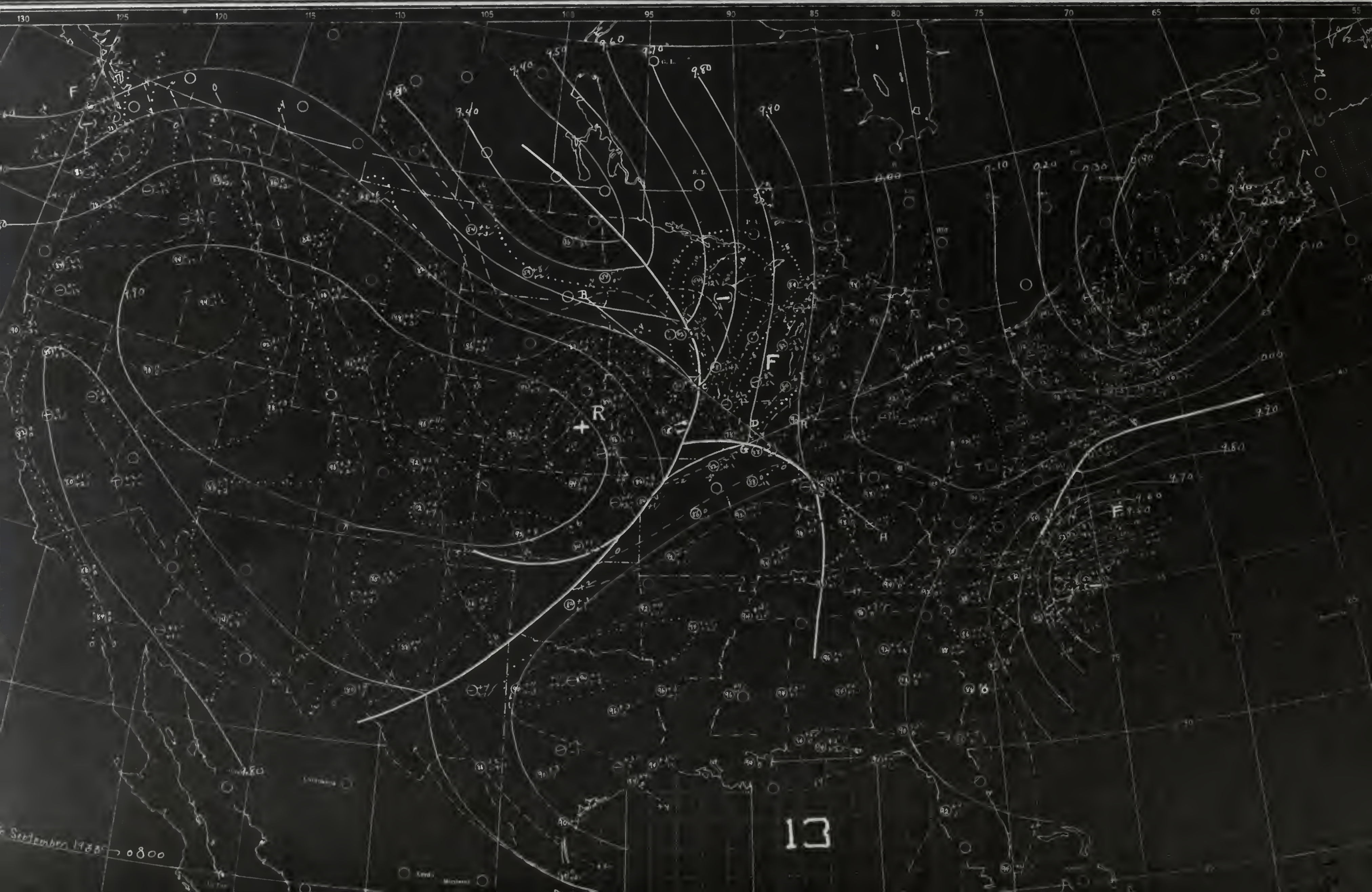
$$= \frac{-5-(-2)-(-2)+(+7)}{\frac{10}{h}} = +\frac{6}{10}\,h$$

h is the distance GR, i.e., the distance between unit isobars along the axis.

This computation tells us that the top of the warm sector will occlude rapidly. We can not compute the occluding velocity along the 29.90 isobar because the isobar does not run symmetrically with the fronts. See the assumptions in K and DP in the derivation of the occluding formula. The isobars being roughly parallel to the Southern portion of the cold FRONT would indicate little movement in this section.

ap AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.



MAP 14

The largest dotted tendency fall is shown at Cape Henry and the largest dashed fall reported is at New York; Hatteras shows the largest tendency rises for both periods. The hurricane continues to move along the anticipated general direction with no indication of a change in that direction taking place. Likewise, the movement of the Western front, now in the central States has been in agreement with computed velocities.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP 15

There being no area of concentration of falling isallobars along the Atlantic Coast to the north of the Hurricane, it continues to remain apparent that the disturbance will continue its trend to the eastward.

Computing the velocity of Point C along line A B, we get, using the frontal velocity formula:

$$C_f = -\frac{0-(+6)}{\frac{10}{h}-0} = .6h = 2.4h \text{ in } 12 \text{ hrs.}$$

Likewise, computing the velocity of D along G E, we get:

$$C_f = -\frac{0-(+4)}{\frac{10}{h}-0} = .4h = 1.6h \text{ in } 12 \text{ hrs.}$$

These two computations, extrapolated for 12 hours give points S and T respectively. This shows good agreement with the observed movement.

The axes are chosen to roughly parallel the isobars behind the front, h being the distances between unit isobars along the axis from the center points, C and D to the next higher isobars, going in the positive direction along the axes.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE. WEATHER MAP. WEATHER BUREAU.

MAP 16

Computing the velocity of Point C on the Front we get:

$$C_f = -\frac{-4 - (+2)}{\frac{10}{h} - 0} = .6h \text{ in } 3 \text{ hrs.}$$

Likewise for Point D, we get:

$$C_f = -\frac{(-2) - (+2)}{\frac{10}{h} - 0} = .4h \text{ in } 3 \text{ hrs.}$$

These velocities, extrapolated for 12 hours give Points S and T respectively, in good agreement with the actual velocity of the Front.

As far as the hurricane is concerned, we see that the area of largest reported falling tendencies continues to be around Long Island and Southern New England; the rises are in the Norfolk-Hatteras area. This indicates continued motion in a northeasterly direction.

Map AA

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP 17

Computing velocity of the Front at Point C:-

$$c_f = -\frac{(-4) - (+3)}{\frac{10}{h} - 0} = .7h \text{ in } 3 \text{ hrs.}$$

Similarly for Point D:-

$$c_f = -\frac{(-1) - (+4)}{\frac{10}{h} - 0} = .5h \text{ in } 3 \text{ hrs.}$$

Giving Points S and T respectively for the position of these points on the Front 12 hours later.

On the past several maps the major, western section of this front has been exposed to a very weak isobaric gradient with the isobars running roughly parallel to the front; this, of course, indicates little movement and computations become impractical.

The past six hours have apparently brought no change in the direction of motion of the hurricane. The Block Island - Nantucket area continues to report the largest minus tendencies indicating that the motion will continue in the same northeasterly direction.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP 18

This map is an example of a situation where numerical computations are not practical. Let us first analyze the tendencies along the front running from Baltimore, northward. We can not accept the tendencies as reported for the previous three hours as representative of the actual instantaneous tendency at the present time. As reported, they are composed first of a rising tendency due to the northeastward movement of the hurricane and then to a falling tendency due to the approach of the front. It then becomes impossible to decide upon the magnitude of the fall associated with the front's approach. This is true about as far north as New Haven. North of that point they may be accepted as more nearly representative. Here, however, we begin to be hampered by scarcity of reports which prevents us from drawing the accurate representation of the pressure and tendency gradients. The importance of the true gradients becomes apparent when we remember that in calculating the movement of the front we are basing our predictions on the magnitude of the gradient at an individual point.

Immediately West of this front in its Northern section the reported tendencies are a combination of pressure changes due to the frontal passage within the tendency period and changes due to the proximity of the hurricane. Here again it becomes impossible to draw isallobars that will represent the true instantaneous tendency.

Turning our attention to the front over Michigan, we can feel fairly sure that the isallobars as faired in behind the front are reasonably accurate. In advance of the front the lack of

MAP 18 (Continued)

reports makes the drawing of both isobars and isallobars problematical. In fact, it can be seen that the minus 08 isallobar is based upon a single report at Detroit and the characteristic at this station makes it even more doubtful. Here again the isobaric gradient will have an enormous effect on the result.

We can, of course, get some idea of the movements of these fronts from a qualitative point of view. Along the northern section of the Eastern front with falls on both sides of the front and the isobars comparatively parallel to the front, we should expect little motion. South of New Haven, however, we realize that the actual falls in advance of the front are larger than reported, and that the isobars show a stronger component perpendicular to the front.. This leads us to expect a bulging out in this section. Along the East-West section of this same front the gradients, both isobaric and isallobaric, are slight and the motion will be small.

The front over Michigan has large rising tendencies to the Northwest and falling tendencies to the Eastward. In its Southern section the gradient again becomes much less. The combination will produce a bulging out similar to that of the Eastern front.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP 19

The same general situation likewise holds for this map, imposing the same limitations upon numerical computations of frontal velocities. The effective rising dotted and dashed isallobars centered over Escanaba and Marquette show less intensity than the corresponding rises on the previous map, hence we should expect the velocity of the front over the Lake region to decrease, since the falls preceding this front are of about the same magnitude as those before. The Western Fronts have active falls in advance of them and with the corresponding rises behind the Westernmost, we anticipate rapid movement of this system to the eastward.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

Map AA.

MAP 20

The hurricane now having passed sufficiently far to the northeastward for its influence no longer to be shown in the tendencies reported in advance of the front over Pennsylvania and New York, we will attempt some computations of the movement of the front in this area. We realize that there is only a small section where computations can be made, but if our interpretations are reasonably accurate, the results should give a fairly true estimate of the movement in this section.

Drawing an axis A B and filling in our formula, we get:

$$C_f = -\frac{-1-(+1)}{-\frac{10}{1.6h}-(-\frac{10}{h})} = \frac{2}{\frac{6}{1.6h}} = \frac{3.2}{6}h$$

taking the movement for 12 hours or 4 periods, we get:

$$\text{disp. } C_f = \frac{3.2}{6}h \times 4 = \frac{12.8}{6}h = 2.1\,h \text{ for a 12 hr. movement.}$$

Applying this movement along our axis, we get the point S.

Starting at the point C, the distance from this point to the 29.80 isobar is our basic h. The distance from the point C to the 29.60 isobar is 1.6 times this length. In going along the axis in the usual positive direction from point C, we are going toward lower pressure, hence $\frac{\partial P_1}{\partial x}$ is negative and the value becomes $-\frac{10}{1.6h}$. Going from the point C toward B we go from low to higher pressure which is positive, but we are going along the axis in the negative direction so our expression $\frac{\partial P_2}{\partial x}$ becomes $-\frac{10}{h}$

Drawing the axis E G and filling in our formula, we get:

$$C_f = -\frac{-1-(+1)}{-\frac{10}{1.5h}-(-\frac{10}{h})} = \frac{2}{\frac{5}{1.5h}} = \frac{3}{5}h \text{ for 3 hours.}$$

MAP 20 (Continued

Multiplying by 4 to obtain the 12 hour movement, we get 2.4 h which gives us the point T as the predicted location 12 hours hence.

The remarks made above relative to the signs of the members apply here also. The basic h is the distance along the E G axis between the point D and the 29.90 isobar.

Drawing the axis J K and proceeding as before we get:

$$C_f = - \frac{-1 - (+1)}{-\frac{10}{1.7h} - \left(-\frac{10}{h}\right)} = \frac{2}{\frac{7}{1.7h}} = \frac{3.4}{7} h \quad \text{for 3 hrs.}$$

Multiplying by 4 we get 2 h as the 12 hour displacement, and laying it off we arrive at the point W.

These 3 points, W, S, and T now represent the predicted location of this section of the front 12 hours hence. A reference to map 22 shows that these points represent a fair mean of the position of the front at that time.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP 21

The computations on the previous map having shown the velocity of the Front over Pennsylvania until it passes off the coast and the quasi-stationary front along the East West line showing no activity, we turn our attention to the system of Fronts moving over the Rocky Mountains. As yet we may not attempt calculations because of the altitude of the reporting stations in this area, but we can see that the concentration of isallobars will give continued rapid motion.

Map AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP 22

The Western system of Fronts continues to be the dominating factor on the map. The same remarks as those on the previous map apply in this case.

ap AA.

U. S. DEPARTMENT OF AGRICULTURE, WEATHER MAP, WEATHER BUREAU.

MAP 23

The warm front passing through Minneapolis has now reached a region where the isobaric gradient approaches that of the true surface gradient and we would expect to be able to compute the velocity of this front. Attempting to compute this velocity, we get a very slow motion as a result.

Referring to the map twelve hours hence, we find our displacement entirely too small. For example, computation of point C along A B gives:

$$c_f = -\frac{-8 - (-7)}{+\frac{10}{h} - 0} = .1\ h \quad \text{and for } 12$$

hours the displacement is found to be .4 h of the point S. Similar computations of points D and M along the axes of their warm sector isobars will give similarly too small results.

The question arises as to the cause of this error. Obviously the isobaric gradient should be reasonably correct, therefore the fault must like in the values of the tendencies used. Glancing at the dashed isallobars in advance and rear of this Front, we see that there are many faired in between relatively few reporting stations. Especially in the rear of the front, the locations of these isallobars as drawn in becomes very questionable. The arrangement of the reporting stations gives no clue to their paths. The isallobars shown on the map were faired in as being the most reasonable. This arrangement is obviously incorrect. Rearrangement of these isallobars would give radically different results. The fault lies, not with the method, but with the scarcity of reporting stations. Had the isallobaric gradient in this region been

MAP 23 (Continued)

small, the true tendency values could have been closer approximated, but in this instance, in the warm sector behind this Front on which we have made our calculations, we have, north of the 29.70 isobar, only four reporting stations in the entire region and the gradient lies between minus 11 and minus 02. Therefore, the arrangement of the isallobars being the cause of our error in computations, this demonstration should serve as an example of the necessity of sufficient reports to determine the true isallobars and that for large isallobaric gradients more reporting stations are needed than in the regions reporting more nearly uniform tendencies. It is obvious that the greater the number of reporting stations on the map, the more reliable should be our results in the use of this method. Hence, in steep isallobaric gradient situations, definite arrangement of the isallobars is most essential.

Looking at the isallobaric system in advance of this warm front and that behind the Westernmost Front, we see large falls in advance and large rises behind this system of three Fronts. Although calculations are unsuccessful, as mentioned, we can see qualitatively that the entire system is subject to a rapid advance, that is, the numerator of any velocity formula across this area would be very large because of this large difference in tendencies. In addition the rapidly falling tendencies between the Fronts indicate rapid occlusion.

Therefore, combining general conditions with individual calculations, large errors of calculations are immediately noticed.

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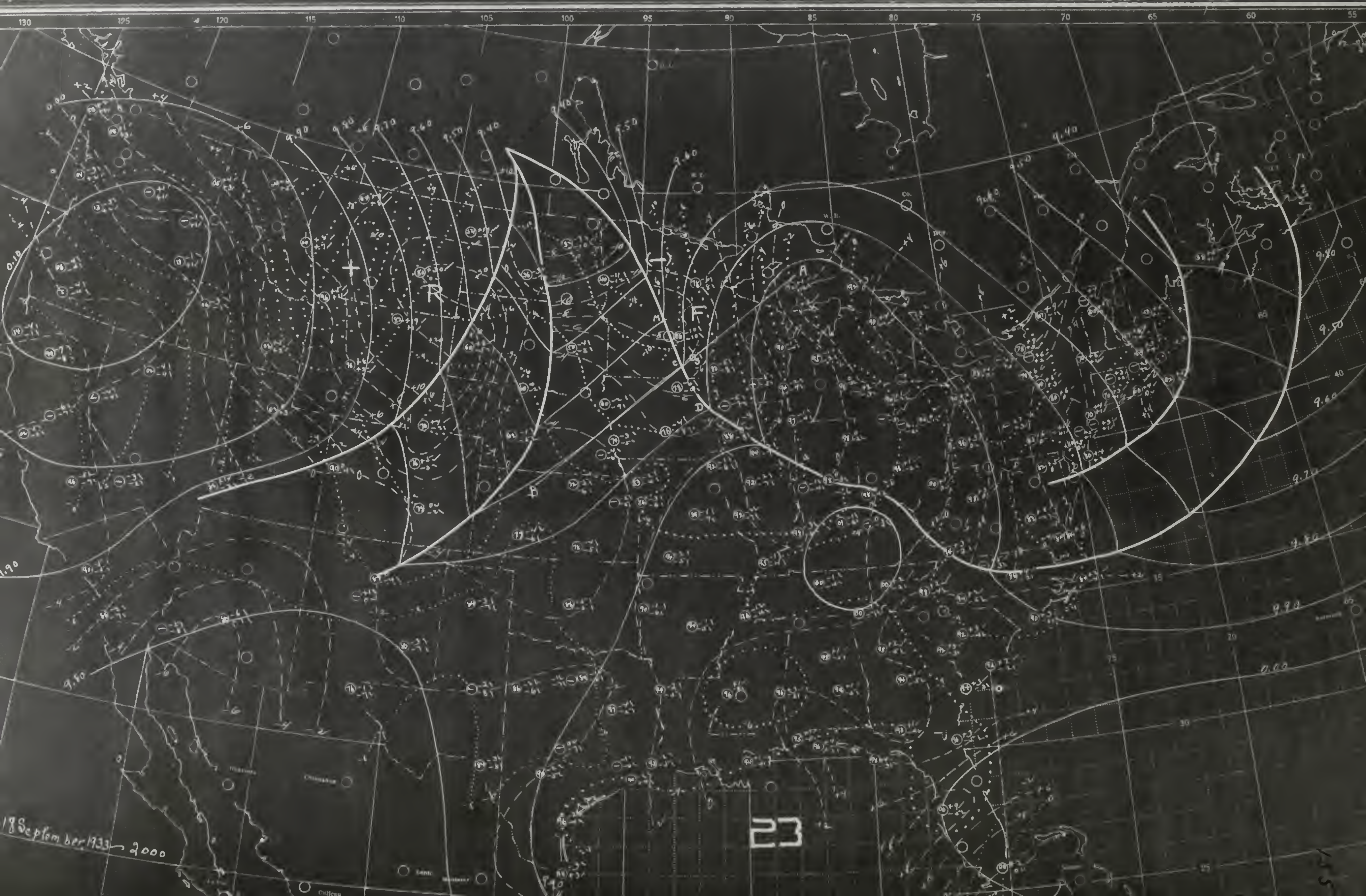

MAP 24

The situation progresses evenly and the general condition remains unchanged on the ensuing maps which are inserted for purposes of checking and continuity.

…ap A.A.

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Map AA.

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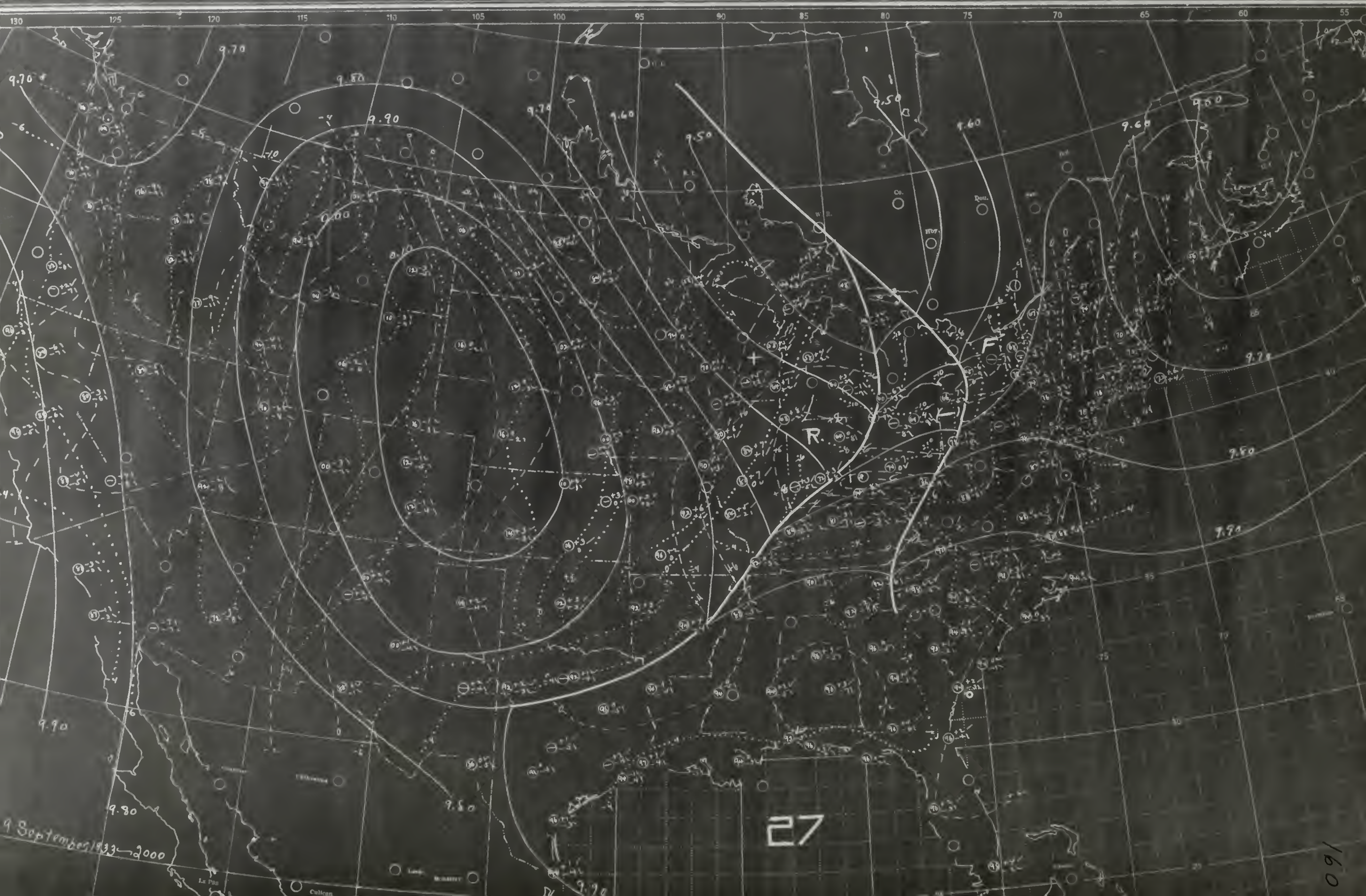

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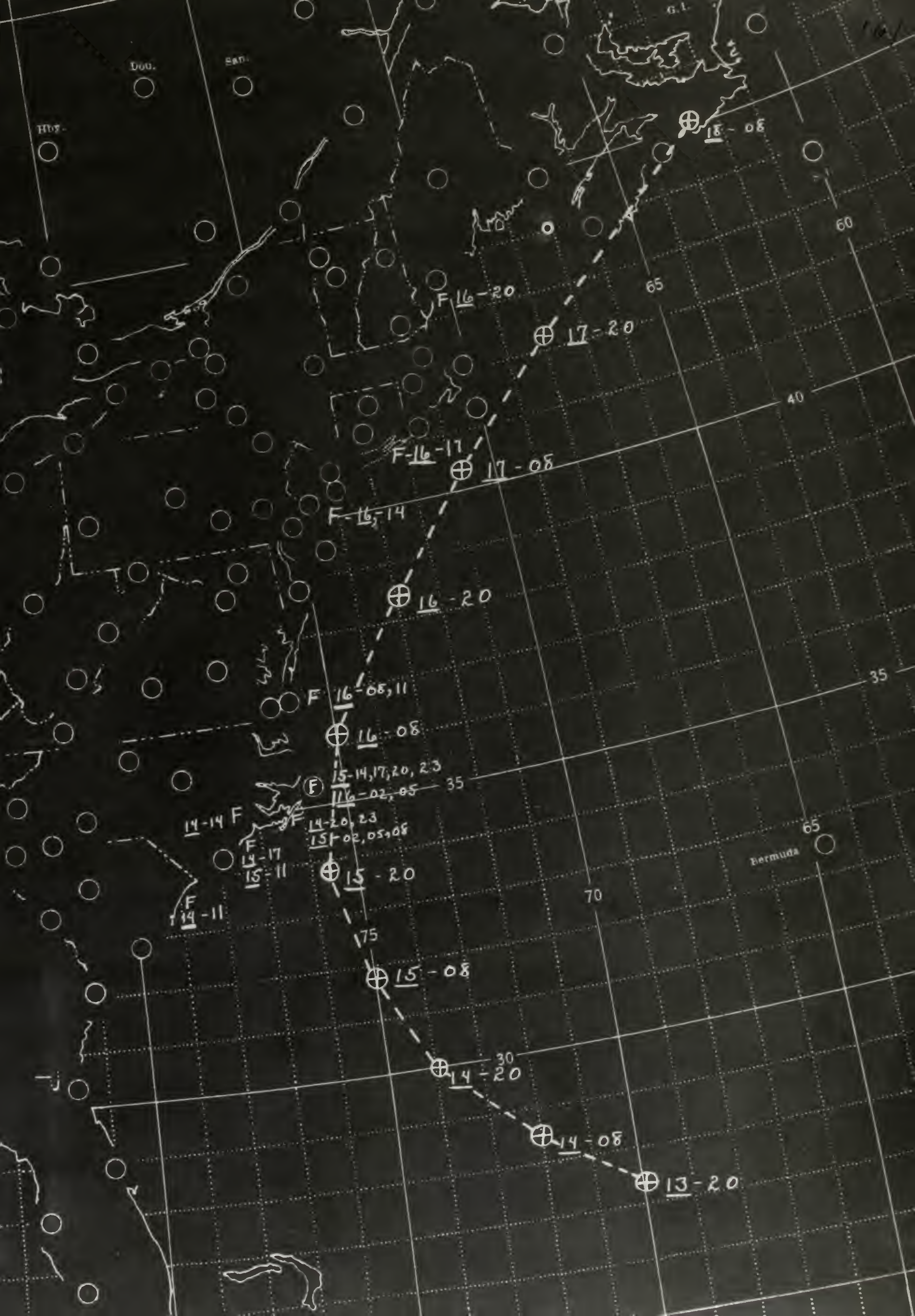
The dotted line represents the path of the hurricane, the encircled crosses are the reported positions of the center at the times indicated alongside. The date is underscored in all cases. The areas of largest negative tendencies are indicated by F. The times shown indicate the three hour period ending at that time. Thus, F 16 11, 14 would mean that the area of largest fall was at the point indicated for the tendency periods ending at 1100 and at 1400 on the 16th. By comparing the dates, one can determine the area of falling pressure at any time as the hurricane progressed. Note the manner in which the area marked F rotated in advance of the center of the hurricane, thereby indicating its direction of approach.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